SCIENTIFIC WRITINGS

OF

JOSEPH HENRY.

VOLUME II.

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PART II.—CONTINUED.

METEOROLOGY: NOTES ON RAIN-GAGES.*

(From the Smithsonian Annual Report for 1855, pp. 229–231.)

- - - Observations have been made at the Smithsonian Institution with rain-gages of different sizes and various forms, the result of which has been to induce a preference for the smaller gages. The one which was first distributed to the observers by the Institution and the Patent Office consists of a funnel terminated above by a cylindrical brass ring, bevelled into a sharp edge at the top, turned perfectly round in a lathe, and of precisely five inches diameter. The rain which falls within this ring is conducted into a two-quart bottle placed below to receive it. To prevent any water which may run down on the outside of the funnel from entering the bottle, a short tube for enclosing its neck is soldered on the lower part of the funnel. The funnel and bottle are placed in a box or small cask sunk in the ground to the level of its surface and provided with a covering board having a circular hole in its centre to receive and support

* [Extract from a Circular of Directions to the meteorological observers of the Smithsonian Institution, prepared by Professors Guyot and Henry (the larger portion by the former), and published in 1850. The circular comprised detailed instructions for the placing, management, and observation of thermometers (free and registering), psychrometers (or wet-bulb thermometers), barometers, rain and snow-gages, wind-vanes, and anemometers, besides suggestions as to personal accounts of the sky, clouds, fogs, &c., as well as of thunder-storms, tornadoes, auroras, and other occasional phenomena.]

the funnel. To prevent the rain-drops which may fall on this board from spattering into the mouth of the funnel some pieces of old cloth or carpet may be tacked upon it.

The object of placing the receiving ring so near the surface of the earth is to avoid eddies caused by the wind, which might disturb the uniformity of the fall of rain.

In the morning, or after a shower of rain, the bottle is taken up and its contents measured in the graduated tube belonging to the apparatus, and the quantity in inches and parts recorded in the register. The tube or gage which was first provided for this purpose will contain when full only one-tenth of an inch of rain, the divisions indicating hundredths and thousandths of an inch. As this however is found to be too small for convenience, another gage—which will contain an inch of rain, and indicating tenths and hundredths—will be sent to observers.

Another and simpler form of the gage has since been adopted by the Institution and Patent Office, to send by mail to distant observers. It is one of those which have been experimented on at the Institution, and is a modification of a gage received from Scotland, which was recommended by Mr. Robert Russell.

It consists of—1. A large brass cylinder, two inches in diameter, to catch the rain: 2. A smaller but longer brass cylinder for receiving the water and reducing the diameter of the column, to allow of greater accuracy in measuring the height: 3. A whalebone scale divided by experiment, so as to indicate tenths and hundredths of an inch of rain: 4. A wooden cylinder to be inserted permanently in the ground for the protection and ready adjustment of the instrument. To facilitate the transportation, the larger and smaller cylinders are connected together by a screw-joint.

To put up this rain-gage for use—1. Let the wooden cylinder be sunk into the ground, in a level unsheltered place, until its upper end is even with the surface of the earth: 2. Screw the larger brass cylinder on the top of the brass tube and place the latter into the hole in the axis of the wooden cylinder, and the arrangement is completed.

The depth of rain is measured by means of the whalebone scale, the superficial grease of which should be removed by rubbing it with a moist cloth before its use. Should the fall of rain be more than sufficient to fill the smaller tube, then the excess must be poured out into another vessel, and the whole measured in the small tube in portions.

Care should be taken to place the rain-gage in a level field or open space sufficiently removed from all objects which would prevent the free access of rain, even when it is falling at the most oblique angle during a strong wind. A considerable space also around the mouth of the funnel should be kept free from plants—as weeds or long grass, and the ground should be so level as to prevent the formation of eddies or variations in the velocity of the wind.

Measuring snow.—To ascertain the amount of water produced from snow, a column of the depth of the fall of snow and of the same diameter as the mouth of the funnel should be melted and measured as so much rain. The simplest method of obtaining a column of snow for this purpose is to procure a tin tube about two feet long (having one end closed) and precisely of the diameter of the mouth of the gage. With the open end downward, press this tube perpendicularly into the snow until it reaches the ground, or the top of the ice, or last preceding snow; then take a plate of tin sufficiently large to cover it, pass it between the mouth of the tube and the ground, and invert the tube. The snow contained in the tube, when melted, may be measured as so much rain. When the snow is adhesive, the use of the tin plate will not be necessary.

From measurements of this kind, repeated in several places when the depth of the snow is unequal, an average quantity may be obtained. As a general average, it will be found that about ten inches of snow will make one inch of water.

ON THE RAIN-FALL AT DIFFERENT HEIGHTS.

(From the Smithsonian Annual Report for 1855, pp. 213, 214.)*

December, 1856.

The subject of the difference of rain at different elevations has received much attention in this country and in Europe; though more investigations are required to settle definitely all the principles on which it depends. It would appear that the greater part of the observed difference is due to eddies of wind, which carry the air containing the falling drops more rapidly over the mouth of the upper gauge than over an equal portion of the unobstructed surface of the ground. Professor Bache found, from a series of observations on the top and at the bottom of a shot-tower in Philadelphia, that not only was there a difference due to elevation, but also to the position of the upper gauge, whether it was placed on the windward or leeward side of the tower. It would also appear, that when the air is saturated with moisture down to the surface of the earth, the descending drop would collect at least a portion of the water it meets with in its passage to the ground, but the amount thus collected would not be sufficient to account for the difference observed. Besides this, the condition does not always exist; the air near the earth is frequently under-saturated during rain, and in this case a portion of the drop would be evaporated, and its size on reaching the earth less than it was above. If the drop is increased by the deposition of new vapor in its descent, then the rain at the bottom ought to be warmer than at the top, on account of the latent heat evolved in the condensation; on the other hand, if the drop be diminished by evaporization during its fall, then the temperature of the rain caught at the greater elevation ought to be in excess. That evaporization does sometimes take place during the fall of rain, would appear from the fact that

* [Remarks appended to an article on the subject, by Prof. O. W. Morris, of New York.]

clouds are seen to exhibit the appearance of giving out rain though none falls to the earth, the whole being entirely evaporated. That the air should ever be under-saturated during rain is at first sight a very surprising fact; it may however be accounted for on the principle of capillarity. The attraction of the surface of a spherical portion of water for itself is in proportion to the curvature or the smallness of the quantity, and hence the tendency to evaporate in a rain-drop ought to be much less than in an equal portion of a flat surface of water.

If the diminution of quantity of rain at the upper station depends principally on eddies of wind, then the effect will be diminished by an increase in the size of the drops, which will give them a greater power of resistance; and the size of the drop will probably be influenced by the intensity of the electricity of the air, as well as by its dryness. The former, as well as the latter, will tend to increase the evaporation from the surface of the drop.

It is a well-established fact, which at first sight would appear to be at variance with the results of observations on towers, that a greater amount of rain falls in some cases on high mountains than on the adjacent plains. For example, the amount of water which annually falls at the convent of St. Bernard is nearly double that which falls at Geneva. This effect however is due to the south wind, loaded with moisture, ascending the slope of the mountain into a colder region, which causes a precipitation of its vapor. From what is here said, it will be evident that the subject of rain is one which involves many considerations, and which still presents a wide field for investigation.

A series of observations has been commenced at the Smithsonian Institution on the quantities of rain at different elevations, as well as on gauges of different sizes and forms, the results of which will be given in one of the meteorological reports.

METEOROLOGY IN ITS CONNECTION WITH AGRICULTURE.

PART I.—GENERAL CONSIDERATIONS.

(Agricultural Report of Commissioner of Patents for 1855, pp. 357-374.)

All the changes on the surface of the earth, and all the movements of the heavenly bodies, are the immediate results of natural forces acting in accordance with established and invariable laws; and it is only by that precise knowledge of these laws, which is properly denominated science, that man is enabled to defend himself against the adverse operations of nature, or to direct her innate powers in accordance with his will. At first sight, meteorology might appear to be an exception to this general proposition, and the changes of the weather and the peculiarities of climate in different portions of the earth's surface to be of all things the most uncertain and furthest removed from the dominion of law; but scientific investigation establishes the fact that no phenomenon is the result of accident, nor even of fitful volition.

The modern science of statistics has revealed a permanency and an order in the occurrence of events depending on conditions in which nothing of this kind could have been supposed. Even those occurrences which seem to be left to the free will, the passion, or the greater or less intelligence of men are under the control of laws—fixed, immutable, and eternal. No one knows the day nor hour of his own death, and nothing is more entirely uncertain in a given case of expected birth, than whether a boy or girl shall be born; but the number out of a million of men living together in one country who shall die in ten, twenty, forty, or sixty years, and the number of boys and girls who shall be born in a million of births, may be predicted from statistical data with almost unerring precision. The statistics of courts of justice have disclosed the astonishing fact,—incomprehensible to our understanding because we do not know the connecting influences which concur to produce the result,—that in every

large country the number of crimes, as well as each kind of crime, can be foretold for every coming year with the same certainty as the number of births and deaths. Of every hundred persons accused before the supreme tribunal in France, sixty-one are condemned; in England, seventy-one; the variation on an average from these numbers hardly amounting to a hundredth part of the whole. Not only the number of suicides in general for several years to come can be foretold with confidence, but also the relative proportion by firearms and by hanging.

The astonishing facts of this class lead us inevitably to the conclusion that all events are governed by a Supreme Intelligence, who knows no change, and that under the same conditions, the same results are invariably produced. If the conditions however are permanently varied, a corresponding change in the results will be observed; for example, the effect of the introduction of an extended system of moral education, in diminishing crime, would be revealed by the statistics.

It is this regularity observable in phenomena when studied in groups of large numbers, which enables us to arrive at permanent laws in regard to meteorology, and hence to predict with certainty the average temperature of a given place for a series of decades of years, and which furnishes the basis (in accordance with the principles of insurance) of a knowledge of what species of plant or animal may be profitably raised in a given locality. We need not however in this branch of knowledge, as in that of the statistics of crime, be confined to the mere discovery of the existence and the measure of the constants of nature; but uniting the results of observations with those of experiments in the laboratory and mathematical deductions from astronomical and other data, we are enabled not only to refer the periodic changes to established laws, but also to trace to their source various perturbing influences which produce the variations from the mean, and thus arrive at an approximate explanation at least, of the meteorological phenomena which are constantly presented to us.

No truth is more important in regard to the material well-being of man, and none requires to be more frequently enforced upon the public mind, than that the improvement and perfection of art depends upon the advance of science. Although many processes have been discovered by accident, and practiced from age to age without a knowledge of the principles on which they depend, yet as a general rule such processes are imperfect, and remain, like Chinese art, for centuries unchanged or unimproved. They are generally wasteful in labor and material, and involve operations which are not merely unessential, but actually detrimental. The dependence of the improvement of agriculture upon the advance of general science, and its intimate connection with meteorology in particular, must be evident when we reflect that it is the art of applying the forces of nature to increase and improve those portions of her productions which are essential to the necessity and comfort of the human race.

Modern science has established, by a wide and careful induction, the fact that plants and animals consist principally of solidified air, the only portions of an earthy character which enter into their composition being the ashes that remain after combustion. All the other parts were originally in the atmosphere, were absorbed from the mass of air during the growth of the plant or animal, and are given back again to the same fountain from which they were drawn, in the decay of the vegetable, and in the breathing and death of the animal.

The air consists of oxygen, nitrogen, carbonic acid, the vapor of water, traces of ammonia, and of nitric acid. A young plant placed in the free atmosphere and exposed to the light of the sun, gradually increases in size and weight by constantly receiving carbon from the carbonic acid of the air, which being thus decomposed, evolves the liberated oxygen. The power by which this decomposition is produced is now known to be due to the solar ray, which consists of a peculiar impulse or vibration, propagated from the distant sun, through a medium filling all space.

It is a principle of nature that power is always absorbed

in producing a change in matter. This change may be permanent, or it may be of such a character as to re-produce the power which was expended in effecting it. For example, the moving power of a cannon ball is permanently expended in passing into the side of a ship; but if the same ball were shot into the mouth of another cannon, and made to compress a spring, the recoiling of the latter would give to the ball, in an opposite direction, precisely the same velocity which it had expended in compressing the spring, supposing nothing lost by friction, &c. This example serves to illustrate the effect of the impulse from the sun. It decomposes the carbonic acid which surrounds the leaf of the plant, or in other words, overcomes the natural attraction between the carbon and the oxygen of which the acid is composed, and in this effort the motions of the atoms of the ætherial medium are themselves stopped. The power however in this case is not permanently neutralized, for when the plant is consumed, either by rapid combustion or by slow decay,—that is, when the carbon and the oxygen are again suffered to rush into union to form carbonic acid,—the same amount of power is evolved in the form of light, heat, or nervous force which was absorbed in the original composition. If the plant moreover be consumed in the animal, the same power is expended in building up the organization, in producing locomotion, and the incessant action of the heart, and the other involuntary movements necessary to the vital process.

Plants are therefore the recipients of the power of the sunbeam. They transfer this power to the animal, and the animal again returns it to celestial space, whence it emanated. To properly so direct this power of the sun-beam that no part of it may run to waste, or be unproductive of economical results, it is essential that we know something of its nature; and the lifetime of labor of many individuals, supported at public expense, would be well applied in exclusive devotion to this one subject. The researches which have been made in regard to it have developed the fact that the impulses from the sun are of at least four different char-

acters, namely, the lighting impulse, the heating impulse, the chemical impulse, and the phosphorogenic impulse; and it has further been ascertained that though each of these impulses may produce an effect on the plant, the decomposition of the carbonic acid is mainly due to the chemical action. A series of experiments is required to determine the various conditions under which these impulses from the sun may be turned to the greatest amount of economical use, and what modifications they may demand, in order to the growth of peculiar plants. It has not yet been clearly ascertained whether some of these emanations cannot be excluded with beneficial result, or in other words, whether they do not produce an antagonistic effect; nor is it known what relative proportions of them are absorbed by the atmosphere, or reflected from our planet by the floating clouds of the air, without reaching the earth. To determine these facts requires a series of elaborate experiments and accurate observations.

We have said that the chemical vibration is that which principally decomposes the carbonic acid in the growth of the plant; but we know that the heating impulse is an auxiliary to this, and that heat and moisture are essential elements in the growth of vegetation. The small amount of knowledge we already possess of the character of the emanations from the sun has been turned to admirable account in horticulture. In this branch of husbandry we seek—even more than in agriculture—to modify the processes of nature; to cultivate the plants of the torrid zone amid the chilling winds of the northern temperate zone, and to render the climate of sterile portions of the earth congenial to the luxurious productions of more favored regions. We seek to produce artificial atmospheres, and to so temper the impulses from the sun that the effects of variations in latitude and the rigor of the climate may be obviated.

From all that has been said therefore it will be evident that the hopes of the future, in regard to agriculture, rest principally upon the advance of abstract science, not upon the mere accumulation of facts, of which the connection and dependence are unknown, but upon a definite conception of

the general principles of which these facts are the result. All the phenomena of the atmosphere should be studied and traced to the laws on which they depend. The labor bestowed upon investigations of this kind is not (as the narrow-sighted advocate of immediate utilitarian results would affirm) without practical importance; on the contrary, it is the basis of the highest improvement of which the art of agriculture is susceptible. On every acre of ground a definite amount of solar force is projected, which may under proper conditions be employed in developing organization; and the great object of the husbandman is to so arrange the conditions, that the least possible amount of this may be lost in un-economical results. Independently however of the practical value of a knowledge of the principles on which the art of agriculture depends, the mind of the farmer should be cultivated as well as his fields, and after the study of God's moral revelation, what is better fitted to improve the intellect than the investigation of the mode by which He produces the changes in the material universe?

The climate and productiveness of a country are determined, first, by its latitude, or its distance on either side of the equator; second, by the configuration of the surface as to elevation and depression; third, by its position, whether in the interior of a continent or in proximity to the ocean; fourth, by the direction and velocity of the prevailing winds; fifth, by the nature of the soil; and lastly, by the cultivation to which it has been subjected.

First, in regard to latitude: The productive power of a soil (other things being the same) depends on two circumstances,—solar radiation and moisture; and these increase as we approach the equator.

If the kind of food were a matter of indifference, the same extent of ground which supports one person at the latitude of 60° would support twenty-five at the equator; but the food necessary to the support of persons in different latitudes varies with respect to quality as well as to quantity; and the other conditions mentioned, with regard to climate, should enter largely into the estimate we form in relation to the actual productiveness of different parallels of latitude.

Though some of the heat of the sun is absorbed in its passage through the atmosphere, yet by far the greater portion (particularly at the equator) arrives at the surface of the earth, is absorbed by the soil, and is imparted to the stratum of air in contact with it. From various determinations it is a well-established fact that the temperature of celestial space beyond our atmosphere is at least 50° below the zero of Fahrenheit's scale. The upper surface of the atmosphere and the Arctic regions must therefore partake of this low temperature, while that of the lower stratum at the surface of the earth is at the equator about 80°. The air therefore diminishes in temperature as we ascend, but the rate of this diminution varies within certain limits in different parts of the earth; and to settle the law of diminution definitely, a series of observations by means of ascents in balloons will be required. For practical purposes however we may assume in the temperate zone that the diminution due to altitudes or mountains is about 1° of Fahrenheit for 300 feet. Furthermore, as we ascend and the pressure of the superincumbent strata is thus reduced, the air becomes lighter; and though the temperature of the several portions diminishes very rapidly, yet the whole amount of heat in each pound of air is very nearly the same. For example, if a certain weight of air were carried from the surface of the earth to such a height that it would expand into double its volume, the heat which it contained would then be distributed throughout twice the space, and the temperature would consequently be much diminished, though the absolute amount of heat would be unchanged. If the same air were returned to the earth whence it was taken, condensation would ensue, and the temperature would be the same as at first.

2. On this principle a wind passing over a high mountain is not necessarily cooled; for the diminution of temperature which is produced by the rarefaction of the ascent would be just equivalent to the increase which is due to the condensation in an equal descent. This would be the case if the air were perfectly dry; but if it contained moisture, para-

doxical as it may seem, it would be warmer when it returned to the lower level than when it left it. In ascending to the top of the mountain it would deposit its moisture in the form of water or snow, and the "latent heat" given out from this, would increase the heat of the air; and when it descended on the opposite side to the same level from which it ascended, it would be warmer on account of this additional heat. The configuration of the surface of our continent has on this account therefore a marked influence on the temperature of its different parts.

3. The effect on its climate, of the position of a country, as regards its proximity to the ocean, will be evident from the facts relative to the radiation and absorption of heat by different substances. All bodies on the surface of the earth are constantly receiving and giving out heat. A piece of ice exposed to the sun sends rays to this luminary, and receives in return a much greater amount. The power however of radiating and receiving heat is very variable in different bodies. Water exposed to the same source of heat receives and radiates in a given time far less than earth; consequently the land (especially in the higher latitudes) during the long summer days or during the growing season, receives much more heat than the corresponding waters of the same latitude; and though the radiation at night is less from the water than the land, yet the accumulating increase of temperature of the latter will be much greater than that of the former. The reverse takes place in the winter. While therefore the mean temperature of the ocean and of the land in the same latitude may remain the same, the tendency of the land is to receive the greater portion of the heat of the whole year during the months of summer, and thus, by a harmonious arrangement with respect to the production of organic life, to increase the effect of the solar radiation, and to widen the limits within which plants of a peculiar character may be cultivated.

Proximity to the sea however has another effect on the climate, which depends upon the currents of the former, by which the temperature of the earth due to the latitude is

materially altered. Heated water is constantly carried from the equatorial regions towards the poles, and streams of cold water returned, by means of which the temperature of the earth is modified and the extremes reduced in intensity. The great currents of the ocean are seven in number, and may be best and most clearly described in connection with an hypothesis as to their origin. For this purpose let us suppose the earth at rest and the equatorial regions continually heated by the sun. In this condition a continuous current of air from the north and another from the south would blow towards the equator, there ascend and flow backward in the upper regions towards the poles. If we next suppose the earth to be in motion on its axis from west to east, and compound the effects of this motion with that of the winds towards the equator on either side, they will not meet directly opposite each other, as in the previous supposition, but at an acute angle, and produce a belt of wind from east to west entirely around the earth in the region of the equator. The continued action of this wind on the surface of the water would evidently give rise to a current of the ocean in the belt over which the wind passed. If now instead of considering the earth entirely covered with water, we suppose the existence of two continents extending from north to south, forming barriers across the current we have described, and establishing two separate oceans, similar to the Atlantic and Pacific, then the continuous current to the west would be deflected right and left or north and south at the western shore of each ocean, and would form four immense whirlpools, namely, two in the Atlantic, one north and the other south of the equator, and two in the Pacific, similar in situation and direction of motion. The regularity of the outline of these whirls will be disturbed by the configuration of the deflecting coasts, and the form of the bottom of the sea, as well as by islands and irregular winds. For a like reason a similar whirlpool will tend to be produced in the Indian Ocean, the current from the east being deflected down the coast of Africa, and returning again into itself along a southern latitude on the western side of Australia. A fifth

whirl exists in this ocean, and in some seasons is at times divided into two, giving rise to the peculiar currents of this part of the earth's surface. Besides these great circular streams, the water supplied by all the rivers emptying into the Arctic basin, as well as that from all the precipitation in this region, returns to the south in a current between Europe and America, which as we shall hereafter see has a very marked influence on the temperature of our coast. A similar current, but more diffuse and less in amount, must constantly flow from the Antarctic regions. In this view we have adopted the hypothesis which ascribes the principal effect to the trade winds. A portion however will be due to the currents produced by the heating of the water itself. To illustrate the effect of these currents on the climate of the United States, let us consider those of the North Atlantic and North Pacific oceans, between which our continent is situated.

The great whirl in the North Atlantic, the western and northern portions of which are known as the Gulf Stream, passes southward down the coast of Africa, crosses the ocean in the region of the equator, is deflected from the northern portion of South America and the coast of Mexico along the United States, and re-crosses the Atlantic at about the latitude of 40°, to return into itself at the place where it started. A portion however of this current (probably owing to the configuration of the bottom) passes off in a tangent to the circumference of the great whirl and flows northward along the coasts of Ireland and Norway. By this current the heated waters of the equator are carried northward along the eastern coast of the United States and precipitated upon the shores of Northern Europe, giving the temperature of a southern latitude even to North Cape, the extremity of Europe, which would otherwise be as cold as Greenland. This stream has less effect upon the climate of the United States than upon that of the western coast of Europe; first, because the prevailing wind is from the west; and secondly, because between our shores and the Gulf Stream the cold polar current intervenes.

In the North Pacific Ocean, on the western side of our continent, the great circle of water passes up along the coast of Japan, re-crosses the ocean in the region of the Aleutian Islands, mingles with the fitful current outward through Behring's Strait, and thence down along the northwest coast of North America. In this long circuit the northeastern portion of it is much more cooled than the similar portion of the whirl of the Atlantic. It therefore modifies the temperature of the northwestern coast and produces a remarkable uniformity along its whole extent, from Sitka to the southern extremity of California. It is an interesting fact, which we have just derived from Captain John Rodgers, that an offshoot from the great whirl in the Pacific, analogous to that which impinges on the coast of Norway, enters along the eastern side of Behring's Strait, while a cold current passes out on the western side, thus producing almost as marked a difference in the character of the vegetation on the two shores of the strait as between that of Ireland and Labrador.

4. The effect of prevailing currents of air on the climate of different portions of the earth is no less marked than that of proximity to the sea. We have seen that on one side of a line over which the sun passes, a current of air flows from the northeast, and on the other from the southeast, giving rise to the trade winds. These winds ascend obliquely, and according to the views of Dove and others, rise to the upper regions of the atmosphere, flow backward towards the poles, and partaking of the rotary motion of the earth, gradually turn to the eastward and approach its surface, producing a series of whirls overlapping each other entirely around the globe. Whatever may be the cause however of the phenomena, Professor Coffin, in his admirable paper on the winds of the northern hemisphere, has shown that from the equator to the pole the whole space is occupied by three great belts, or zones, of prevailing wind: the first extends from the equator to an average latitude of 35° north, in which the current is from the northeast, constantly growing less intense as we approach the northern limit; the second

is that from 35° to about 60°, the current from the west being more intense in the middle of the belt, and gradually diminishing on either side almost into a calm; third, from 60° to the pole, or rather to a point of greatest cold in the Arctic regions, the wind is in a northeasterly direction.

The first of these belts would constitute what is called the trade winds, produced as we have said, by the combined effects of the heat of the sun and the rotation of the earth; the second is the return trade, and the third the current which would be produced by an opposite effect to that of the rarefaction of the air by the sun at the equator, namely, the condensation of the air by the cold portion of the earth. The air should flow out in every direction from the coldest point, and combining its motion towards the south with the rotation of the earth, it should take a direction from the east to the west or become a northeasterly wind.

The effects which these currents must have upon the climate of the United States will be made clear by a little reflection. The trade winds within the tropics, charged with vapor, in their course towards the west impinging upon the mountainous parts of South America, will deposit their moisture on the eastern slope and produce a rainless district on the western side. Again, a lower portion of the Atlantic and Gulf trade wind will be deflected from these mountains along the eastern coast of the United States and through the valley of the Mississippi as a surface wind, and thus give rise to our moist and warm summer breezes from the south, while the principal or upper portion of the trade wind (or the return westerly current) sweeping over the Pacific Ocean, and consequently charged with moisture, will impinge on the Coast Range of mountains of Oregon and California, and in ascending its slopes deposit moisture on the western declivity, giving fertility and a healthful climate to a narrow strip of country bordering on the ocean and sterility to the eastern slope. All the moisture however will not be deposited in the passage over the first range, but a portion will be precipitated on the western side of the next, until it reaches the eastern elevated ridge of the Rocky

Mountain system, where we think it will be nearly, if not quite, exhausted. East of this ridge, and as it were, in its shadow, there will exist a sterile belt, extending in a northerly and southerly direction many hundred miles. The whole country also included between the eastern ridge of the Rocky Mountains and the Pacific Ocean, with the exception of the narrow strip before mentioned, will be deficient in moisture, and on account of the heat evolved (as before shown) by the condensation of moisture on the ridges, will be at a much higher temperature than that due to latitude. This mountain region and the sterile belt east of it occupy an area about equal to one-third of the whole surface of the United States, which with our present knowledge of the laws of nature and their application to economical purposes must ever remain of little value to the husbandman.

According to this view, the whole valley of the Mississippi owes its fertility principally to the moisture which proceeds from the Gulf of Mexico, and the inter-tropical part of the Atlantic Ocean. The Atlantic Gulf Stream therefore (as already remarked) produces very little effect in modifying the climate of the northern portion of the United States; both on account of the cold polar current which intervenes between it and the shore, and because of the prevalent westerly wind, which carries the heat and moisture from us, and precipitates them on the coast of Europe.

5. The influence of the nature of the soil on the climate of a country, may be inferred from its greater or less power to absorb and radiate heat, and from its capacity to absorb, or transmit over its surface, the water which may fall upon it in rain, or be deposited in dew. In the investigation of this part of the subject, the observations of the geologist, and the experiments of the chemist and the physicist must be called into requisition.

6. In regard to the influence of *cultivation* on the climate of a country much also may be said, though at first sight it might appear that man, with his feeble powers, could hope to have no influence in modifying the action of the great physical agents which determine the heat and moisture of

any extended portions of the globe. But though man cannot direct the winds, nor change the order of the seasons, he is enabled, by altering the conditions under which the forces of nature operate, materially to modify the results produced; for example, removing the forests from an extended portion of country exposes the ground to the immediate radiation of the sun, and increases in many cases the amount of evaporation; in other places it bakes the earth and allows the water to be carried off to the ocean in freshets, and in some instances, in destructive inundations.

Drying extensive marshes, or the introduction of a general system of drainage, has a remarkable influence in modifying the temperature. The water which would evaporate, and by the latent heat thus absorbed, would cool the ground, is suffered to pass through it to the drain beneath, and is thus carried off without depriving the earth of a large amount of heat, which would otherwise be lost. Besides this, the removal of forests gives greater scope to the winds, which are hence subjected to less friction in their passage over the earth.

The whole subject of the removal of forests is one which deserves more attention than it has usually received. In the progress of settlement, it is evident that a great portion of the wooded land of a new country must give place to the cleared field, in order that man may reap the rich harvest of the cereals, which in his civilized condition are necessaries as well as luxuries of life; yet the indiscriminate destruction of the forests is of doubtful propriety. By the judicious reservation of trees along the boundaries of certain portions of land, in accordance with the known direction of the prevailing wind, the climate may be ameliorated within a restricted portion of the earth, both for the production of plants and animals. While in some parts of the country the clearing of nearly all the ground is absolutely necessary for agricultural purposes, in others it may be profitable to allow forests of considerable extent to remain in their pristine condition. Cases of this kind however can be determined only by the particular climate of each district of the country.

It is now an established truth that certain localities are screened from miasmatic influence by the intervention of trees. A more general recognition of this fact might add much to the healthfulness of localities in other respects highly desirable.

The solar rays, in passing through the atmosphere, do not heat it in any considerable degree, but they heat the earth against which they impinge; therefore the temperature of the lower stratum of air is derived, directly or indirectly, from the soil on which it rests; and this temperature, as has been remarked, will depend upon whether the surface be marshy or dry, clothed with herbage, or covered with sand, clay, or an exposed rock. From this fact it is evident that man has, in this particular also, considerable power in modifying the climate of portions of the earth; and history furnishes us with many examples in which great changes, within human control, have been produced in the course of ages. Nineveh and Babylon, once so celebrated for their advance in civilization and opulence, and Palmyra and Baalbec, for their magnificence, offer at this day to the traveller the site of ruins which attest their past greatness, in the midst of desolation. Canaan, described in the Bible as a fertile country, "flowing with milk and honey," is now nearly deprived of vegetation, and presents a scene of almost uninterrupted barrenness. The climate of these countries is undoubtedly modified by the present state of the surface, and might again be ameliorated by cultivation, were the encroachments of the sands of the desert stayed by borders of vegetation of a proper character. Many parts, even of our own country, which now exhibit a surface of uninterrupted sand, may be rendered productive, or covered with trees and herbage.

A series of observations on the progress of temperature below the surface, in different parts of the country, and even in different fields of the same plantation, would be of value in ascertaining the proper time to introduce the seed, in order that it might not be subjected to decay by premature planting, or lose too much of the necessary influence of

summer by tardy exposure in the ground. This may perhaps be most simply effected by burying a number of bottles filled with water at different depths in the ground, say one at the depth of 6 inches, another at 12, and a third at 18 inches. These in the course of time would take the temperature of the earth in which they were embedded, and would retain it sufficiently long unchanged, to admit of its measurement, by inserting a thermometer into the mouth of the bottle.

No improvement is more necessary, for rendering the art of agriculture precise, than the introduction into its processes of the two essential principles of science, namely, those of weight and of measure. All the processes in our manufactories, on a great scale, which were formerly conducted by mere guesses, as to heat and quantities, are now subjected to rules, in which the measure of temperature and the weight of materials are definitely ascertained by reliable instruments.

The foregoing are general views as to the great principles which govern the peculiarities of climate, and especially that of the United States, the truth of which, in reference to our continent, and the modifications to which they are to be subjected, are to be settled by observations in the future.

In order however that the science of meteorology may be founded on reliable data, and attain that rank which its importance demands, it is necessary that extended systems of co-operation should be established. In regard to climate, no part of the world is isolated; that of the smallest island in the Pacific is governed by the general currents of the air and of the waters of the ocean. To fully understand therefore the causes which influence the climate of any one country, or any one place, it will be necessary to study the conditions, as to heat, moisture, and the movements of the air of all others. It is evident also that, as far as possible, one method should be adopted, and that instruments affording the same indications, under the same conditions, should be employed.

It is true that, for determining the general changes of

temperature, and the great movements of the atmosphere of the globe, comparatively few stations of observation, of the first class, are required; but these should be properly distributed, well furnished with instruments, and supplied with a sufficient corps of observers, to record at all periods of the day the prominent fluctuations. Such stations however can only be established and supported by the co-operation of a number of governments.

A general plan of this kind for observing the meteorological and magnetical changes more extensively than had ever before been undertaken, was digested by the British Association in 1838, in which the principal governments of Europe were induced to take an active part; and had that of the United States and those of South America joined in the enterprise, a series of watch-towers of nature would have been distributed over every part of the earth. The following were the stations of the several observatories established: Those of the English Government were at Greenwich, Dublin, Toronto, St. Helena, Cape of Good Hope, Van Dieman's Land, Madras, Simla, Singapore, and Aden. The Russian observatories were at Boulowa, Helsingfors, Petersburg, Sitka, Catherineburg, Kasan, Barnaoul, Nicolaieff, Nertschinsk, Tiflis, and Pekin. Those of Austria were at Prague and Milan. In the United States, an observatory was established at Girard College, under the direction of Professor Bache. The French Government had one at Algiers; the Prussian Government, one at Breslau; the Bavarian Government, one at Munich; and the Belgian, one at Brussels. There was one at Cairo, supported by the Pasha of Egypt, and one in India, at Travandrum.

These observatories were established to carry out a series of observations at the same moment of absolute time, every two hours, day and night, during three years, together with observations once every month, continuing 24 hours, at intervals of five minutes each. They were all furnished with standard instruments, and followed instructions adopted by the directors of the general system. Operations were commenced in 1839, and in a number of cases, were continued

through nine years. The number of separate observations amounted to nearly six millions, which required at least as much labor for their reduction as that expended in the observations themselves. The comparisons of these observations are still in progress, and will occupy the attention of the student of magnetism and meteorology for many years to come. The system was established more particularly to study the changes of the magnetic needle, and on this sub ject alone it has afforded information of sufficient importance to repay all the labor and time expended on it. It has shown that the magnetic force is scarcely constant from one moment to another, that the needle is almost incessantly in motion, that it is affected by the position of the sun and moon, and by perturbations, connected with meteorological phenomena, of a most extraordinary character.

In regard to meteorology, this system furnished reliable data for the great movements of the atmosphere, and the changes in its thermal and hygrometric condition. But to obtain a more minute knowledge of the special climatology of different countries, it is necessary that a series of observations, at a great many places, should be continued through a number of years, and at stated periods of the day—not as frequent as those of the observations we have mentioned, but embracing as many elements, and even adding to these, as new facts may be developed or new views entertained. In many countries accordingly, provision has been made by their respective governments, for continued though local systems of this kind. The Government of Prussia appears to have taken the lead in this important labor, and its example has been followed by those of Great Britain, Russia, Austria, Bavaria, Belgium, Holland, and France. In these countries, regular and continuous observations are made with reliable instruments, on well-digested plans.

Though the Government of the United States took no part with the other nations of the earth in the great system before described, yet it has established and supported for a number of years a partial system of observation at the different military posts of the army. Among other duties

assigned to the surgeons, at the suggestion of Surgeon General Lovell, was that of keeping a diary of the weather, and of the diseases prevalent in their vicinity. The earliest register received, under this regulation, was in January, 1819. The only instruments at first used were a thermometer and wind-vane, to which in 1836, a rain-gauge was added. The observations were made at 7 A. M. and 9 P. M., and the winds and weather were observed morning, noon, and evening. It is to be regretted that in 1841, the variable hour of sunrise was substituted for that of 7 A. M., since the latter admits of an hourly correction which cannot be applied to the former, except at the expense of too great an amount of labor.

The results of the observations for 1820 and 1821 were published at the end of each year; those from 1822 to 1825, inclusive, were issued in the form of a volume by Surgeon General Lovell; those from 1826 to 1830, and from 1830 to 1842, inclusive, were prepared and published in two volumes, under the direction of the present Surgeon General, Dr. Thomas Lawson. At the commencement of 1843 an extension of the system was made by the introduction of new instruments, and an additional observation to the number which had previously been recorded each day, and hourly observations for twenty-four hours were directed to be taken at the equinoxes and solstices.

During the past year a quarto volume has been published, which contains the results of the observations of the thermometer, direction and force of winds, clearness of sky, and fall of rain and snow, during a period of twelve years, from the first of January, 1843, to January, 1855, arranged in monthly tables and annual summaries. To these are added consolidated tables of temperature and rain for each separate station, comprising the results of all the thermometric observations made by medical officers since 1822, and of all measurements of rain and snow since the introduction of the rain-gauge in 1836.

The tabular part of this volume contains the most important results of the observations of the army system of registration, and will be considered the most valuable contribu-

tion yet made toward a knowledge of the climatology of the United States. Truth however will not permit us to express the same opinion in reference to the isothermal charts which accompany this volume. These we consider as premature publications, constructed from insufficient data, and on a principle of projection by which it is not possible to represent correctly the relative temperatures in mountainous regions.

With the learning and zeal for science possessed by the officers of the United States army, and the importance which they attach to meteorology, in its connection with engineering and topography, it is hoped that this system may be further extended and improved, that each station may be supplied with a compared thermometer and psychrometer, and that at a few stations a series of hourly observations may be established, for at least a single year. The present Secretary of War, we are assured, would willingly sanction any proposition for the improvement of this system, and we doubt not the Surgeon General is desirous of rendering it as perfect as the means at his disposal will permit.

A local system of meteorological observations was established in the State of New York in 1825, and has been uninterruptedly conducted from that time until the present. Each of the academies which participated in the literature fund of the State was furnished with a thermometer and rain-gauge, and directed to make three daily observations relative to the temperature, the direction of the wind, cloudiness, &c. The system was re-modeled, in 1850, so as to conform to the directions of the Smithsonian Institution, and a considerable number of the academies were furnished with full sets of compared instruments, consisting of a barometer, thermometer, psychrometer, rain-gauge, and wind-vane.

A summary of the results of the observations from 1826 to 1850, inclusive, has just been published by the State of New York, under the direction of the regents of the University. They are presented in the form of a quarto volume, to which is prefixed a map of the State, showing the

direction of the wind and the position of each station. This volume, the computations for which were made by Dr. Franklin B. Hough, is also a valuable contribution to meteorology, and does much credit to the intelligence and perseverance of those who introduced and have advocated the continuance of this system, and to the liberality of the State which has so long and so generously supported it.

A system of State observations in Pennsylvania was established in 1837. For this purpose the Legislature appropriated $4,000, which sum was placed at the joint disposal of a committee of the American Philosophical Society and the Franklin Institute. The results of this system have not yet been presented to the world in a digested form.

Another State system was established in Massachusetts in 1849, the records of which have been presented to the Smithsonian Institution, and will be published, in considerable detail, either at the expense of the State or of the Smithsonian fund.

A system of meteorological observations was established by the Smithsonian Institution in 1849, the principal object of which was to study the storms that visit the United States, particularly during the winter months. This system, which has been continued up to the present time, was afterward extended, with a view to collect the statistics necessary to ascertain the character of the climate of North America, to determine the average temperature of various portions of the country, and the variations from this at different periods of the year. It was intended to reduce, as far as possible, the several systems of observations to one general plan which had previously been established, and to induce others to engage in the same enterprise. But in order that the results might be comparable with those obtained in other countries, it was regarded as of primary importance that the instruments should be more accurate than those which might be requisite for the mere determination of the phenomena of storms. The Institution therefore procured standard barometers and thermometers from London and Paris, and with the aid of Professor Guyot, a distinguished meteorologist, copies of

these were made, with improvements, by Mr. James Green, a scientific artisan, of New York. A large number of these instruments have been constructed and sold to observers. Full sets have been furnished by the Institution to parties in important positions, and in some cases, half the cost has been paid from the Smithsonian fund.

A growing taste having been manifestly created for the study of practical meteorology, directions for observations and a volume of tables for their reduction, have been prepared and widely circulated at the expense of the Institution. It has also distributed blanks to all the observers of the different systems alluded to, except those of the army, and has received in return, copies of all the observations which have been made. It has in this way accumulated a large amount of valuable material relative to the climate of this country and to the character of the storms to which it is subjected. The completeness and accuracy of the observations have also increased from year to year; and by an arrangement which the Institution has now made with the Patent Office, it is hoped that the system will be extended, and its character improved.

It being manifest from the foregoing statements, and from other evidences, that much interest is awakened in this country on the subject of meteorology, it is hoped that the means may be afforded for reducing and publishing the materials which have been and may hereafter be accumulated, and that important results to agriculture, as well as to other arts, may be hence deduced.

*Description of the Tables.**

The numbers given in the accompanying meteorological tables are mostly those indicating average or mean results. The principle of deducing general laws from a multiplicity of facts or observations—though liable in themselves to error, is of the greatest value in modern science. If we observe

* [Twenty pages of Meteorological Tables following this part are omitted in the present re-print.]

the temperature of a given place every hour in the day, add all the observations into one sum for a year, and divide by the number of hours in a year, we shall get the mean annual temperature. By this method of observation we shall ascertain the warmest and the coolest hours of each day, and by repeating the same process for a number of years, we shall learn the temperature of each hour, eliminated from all perturbations, and in this way arrive at truths which could not be obtained by any other means. If we examine the individual records we shall find the warmest time to recur, on different days, at different hours. We know however that if there were no perturbing influences the warmest period of the day would be that at which the heat received from the sun is just equal to the cooling of the earth by radiation into space. At every instant from the rising of the sun previous to this the earth would be receiving more heat than it gave off, and hence the temperature would constantly increase until the heating and cooling were equal. After this the earth would give off more heat than it would receive, and the temperature would begin to descend. On individual days however, clouds may intervene, or winds of varying temperatures and velocities may prevail, so as to change the hour of maximum heat; but as these are not periodical or governed by recurring laws, the probability is that they will act in opposite directions; that is, on some days hasten the maximum period, and on other days retard it, and thus in the course of a year, or several years, neutralize each other. The method of averages therefore enables us to separate the effects produced by irregular variations from those which are due to permanent causes. The latter are called periodic variations, while to the former has been given the name of non-periodic. By continuing the observations for a number of years, in ascertaining the temperature at a given place, we find by the method we have explained a result from which that of the individual years will oscillate on either side within certain limits, while for two separate decades of years it will scarcely differ at all; and this is the mean temperature of the place. The same

statement may be made in regard to the other elements of meteorology, and the result of all the observations may be divided into two great classes, periodical and non-periodical, though by a very long series of observations, it may happen that a phenomenon which at first may appear entirely fitful, will afterwards prove to be recurring; and at all events the non-periodic variations are found to be restricted within definite limits, the maximum amount of which it is highly necessary to obtain.

The first element given in the tables is that of the mean height of the barometer from month to month. This is perhaps less immediately essential to the agriculturist than any other meteorological element. It is however of much importance in determining the progress of storms and the area over which the commotions of the atmosphere connected with them are perceptible, though no violent disturbances may be observed. For example, if the barometer on a given day is higher or lower than the average for the month, we are then convinced that it is subjected to some unusual perturbation; and by drawing a line on a map through all the places at which a given amount of disturbance is felt at a particular time, we are enabled to trace the boundary of a storm, and to indicate its progress, development, and end. For this purpose it is not necessary even that the barometers should be strictly comparable with each other; it is only necessary that the results should be comparable among themselves. When the barometers have been accurately compared with each other, (as in the case of those of Green, of New York, constructed under the direction of the Smithsonian Institution,) they afford the data for determining the relative elevation of different places of observation above the level of the sea.

The indications of the barometer, compared with those of the hygrometer, thermometer, and wind-vane, furnish us with a method of predicting changes in the weather. These however in many cases will be found to depend upon rules applicable to particular places, and which can only be determined by a long series of local observations.

The next element given in the tables is the mean monthly temperature. By comparing this with the average deduced from a number of years' observations we are enabled to ascertain the variations of each month from the normal temperature of the same month as deduced from a series of years, and to compare the temperature of the "growing" portions of different years with each other. When experiments shall have been made upon the amount and distribution of heat necessary to give the best development to particular plants, by a table of this kind we are enabled to select the months best suited to their cultivation. Moreover, each plant requires a certain amount of heat for its proper growth, though this amount may vary considerably in intensity; for example, a comparatively low degree of heat may be compensated by its longer continuance. This rule however is confined within certain limits; for if the temperature rises above a given degree, or falls below a particular point, the vitality of the plant may be destroyed. By a well-conducted series of experiments and observations the agriculturist may be enabled to determine, without a ruinous series of actual trials, what plant may be safely cultivated in a given place.

Besides the mean temperature, the extremes are also given, and these are of essential importance in determining the variations of temperature to which the plant is to be subjected. The length of the growing summer in a given year, and in a particular place, may for instance be measured by the interval which occurs between two killing frosts.

The next element in order, presented in the accompanying tables, is that of the moisture; and this is of much importance in judging of the productiveness of different years and different places. Unfortunately however, comparatively few observations are regularly made on the variations of moisture in the atmosphere, in the United States. It is to be hoped that our returns for another year will indicate an increased number of the stations where valuable observations of this kind are taken. The figures in the tables do not indicate the actual amount of water, for example, in a

cubic foot of air, but the fractional part of the whole amount necessary to produce entire saturation; thus if saturation is represented by 100, 57 indicates that this number of parts of water is contained in the air, or that it is a little more than half saturated. We are obliged to adopt this method of representation, because the relative moisture and dryness of the air depend upon the temperature, and not on the absolute quantity of vapor present. Thus air at 32° F., which contains as much water as it can hold, or in other words is saturated would by heating, become exceedingly dry, though containing absolutely the same amount of water. The relative dryness is indicated by the complement of the numbers in the table, and consequently may be found by subtracting these numbers from 100. The state of our feelings is much more affected by the moisture of the atmosphere than by the temperature, and the sensation called "closeness" is principally due to the great amount of humidity, or in other words, to the diminution of the dryness of the air, which prevents evaporation from the surface of the body, and its attendant cooling effects. A series of observations on the relative humidity in the regions west of the Mississippi, and the northern portions of the middle part of our continent, in connection with the different winds, would be highly interesting in determining the source of the vapor in these regions, as well as settling definitely the fact in regard to their average productiveness.

Another element intimately connected with the moisture in the air, is the amount of rain and snow, particularly the former. Besides the whole amount which falls during a year, it is necessary to know the relative quantity which falls in different months. A large amount of rain may fall at once, and a greater relative proportion of it will be carried off, before the earth can have time to be fully saturated through the streams of creeks and rivers, and thus do much less in the way of fertilizing the earth, than if the same amount were distributed over a longer period.

The indications of the rain, as of the other elements, would be more interesting, could they be compared with the average

amount deduced from a series of observations made through a number of years.

The direction of the wind, as well as the amount of cloudiness and sunshine, besides being of much importance in determining the meteorological elements of the climate of a country, are of interest to the farmer in comparing them with the other elements with which it is intimately connected, and thus deducing rules for the prognostication of the weather.

METEOROLOGY IN ITS CONNECTION WITH AGRICULTURE.

PART II.—GENERAL ATMOSPHERIC CONDITIONS.

(Agricultural Report of Commissioner of Patents, for 1856; pp. 455–492.)

In the last Agricultural Report of the Patent Office I gave an account of the several systems of meteorology now co-operating in this country to advance the science, and also endeavored to show the importance of this branch of knowledge in its connection with agriculture. I propose in this Report and the subsequent ones to continue the subject, and to present some of the physical laws on which meteorology depends, the general principles at which it has arrived, and their application to the peculiarities of the climate of the United States. An exposition of this kind presented to the farmer through the Agricultural Report it is thought will serve to awaken a more lively interest in the subject, will tend to diffuse a knowledge of the advantages of general principles, and will convey information not readily accessible, and which in reality does not elsewhere exist in the condensed form in which it will be here given.

Perhaps no branch of science has given rise to more speculation or excited a greater amount of angry controversy than that relating to the nature and interpretation of atmospheric phenomena. The former may arise from the dependence of man for health and comfort on the state of the weather, and the latter from the limited sphere of individual observation to which the cultivators of this branch are generally confined. While the astronomer, without quitting his observatory (if situated near the equator) can watch the motions of all the heavenly bodies as they present themselves in succession to his telescope, the meteorologist can take cognizance only of the changes which occur immediately around him, and hence the origin of partial views and imperfect generalizations. Controversies in this science, as in most others, may frequently however be referred to the partiality we entertain for the products of our own minds. Truth, as has been properly said, belongs to mankind in general; our

hypotheses belong exclusively to ourselves, and we are frequently more interested in supporting or defending these than in patiently and industriously pursuing the great object of science, namely, the discovery of what *is*.

In the account of meteorology which it is proposed to give, the writer has no hypotheses or theories of his own to support, but will endeavor to confine his statements to the exposition of such principles as are generally recognized at the present day; and if hereafter it shall be found that views have been presented in this paper which cannot be sustained, he will point out in the subsequent Reports the errors which may have been committed. The expounder of science, unlike the politician, is at liberty to change his opinions when they are found to be at variance with the actual condition of things. Indeed, in the investigation of nature, we provisionally adopt hypotheses as antecedent probabilities, which we seek to prove or disprove by subsequent observation and experiment; and it is in this way that science is most rapidly and securely advanced.

Some parts of our subject, as will be seen, are intimately connected with leading questions of the day; and on this account it might be considered prudent to avoid allusion to them. But the great aim of science is the discovery of truth; and the proverbial veneration entertained for it by the human mind is a sure indication that truth, and the whole truth, will always be conducive to the real progress of nations or individuals, and that to present it simply as a proposition without special application is the best means of supplanting error. We hold in high veneration the plan of government established by the wisdom of our forefathers; but we cannot be blind to the fact that it required a peculiar theatre for its application, a wide territory of fertile soil and genial climate, well fitted to reward the labors of the husbandman and to promote the health of his body and the vigorous activity of his mind. Next to our political organization, under Providence our prosperity has mainly been promoted by the ample room afforded us for expansion over the most favored regions of this continent. It becomes therefore important

for us to ascertain the natural limits, if there are any, to the arable portion of our still untenanted possessions, and to determine, if possible, what parts of it are best fitted by climate and soil for the future operations of the husbandman. The data do not exist at present for the definite solution of this problem; but it is one object of the systems of meteorology now in operation in this country to collect the facts by which it may be fully solved. In the United States agriculture as a science has been up to this time of comparatively little importance; refined processes of cultivation are not required where the products of millions of acres of virgin soil can be gathered without skill and with comparatively little labor. It is only when the organic power and material which Nature has thus stored up in the primitive earth have been to a greater or less extent exhausted, that scientific processes must be adopted in order to secure the continued production of ample harvests. The time is at hand when scientific agriculture can no longer be neglected by us; for however large our domain really is, and however inexhaustible it may have been represented to be, a sober deduction from the facts which have accumulated during the last few years will show that we are nearer the confines of the healthy expansion of our agricultural operations over new ground than those who have not paid careful attention to the subject could readily imagine. We think it will be found a wiser policy to develop more fully the agricultural resources of the States and Territories bordering on the Mississippi, than to attempt the further invasion of the sterile waste that lies beyond.

The laws of nature are all simple and readily comprehended by a mind of ordinary capacity, when separately announced; but when the conditions under which they operate are varied, and a number of forces are called into action, the resulting phenomena frequently become so complex that their investigation transcends not only the ordinary logic of the most gifted mind, but even the more powerful analysis of the mathematician. It has been well said by Professor Benjamin Peirce, of Cambridge, that had the lot of man been cast

upon one of the outer planets of our system, the phenomena of the motions of the heavenly bodies, as viewed from that point, would have been so complex and apparently irregular, that our present state of civilization (resting as it does on the principles of science beginning with astronomy, the most perfect) would not have existed: man would never have arrived at the definite idea and the conclusive evidence of the universality of causation. In other words, that amid all the apparently confused and accidental occurrences which we observe, a few simple laws (constantly diminishing in number as our views become more extended) govern all events, whether they be those which we refer to order and succession, or those which in our ignorance we ascribe to to chance. Astronomy is the most perfect of all the sciences, not only because it has been longer studied, but more especially because it is the simplest exhibition of the laws of force and motion; and yet even in this science where all the data are furnished, the introduction of a few conditions renders a problem too complex for direct solution. For example, to determine the path described and the time of revolution of a single planet round the central body by the application of the laws of motion and gravitation is a simple problem, which was solved at an early period in the history of astronomy. When however a third body was introduced, such for example as the moon, in addition to the earth and sun, the problem baffled for a long time the skill of the first mathematicians of the age; and even yet a direct *à priori* solution of all the results which will be produced by the mutual action of a series of planets revolving round the sun has not been effected, and recourse is had to indirect methods of approximation. Had man confined his observations to the complex and multiform changes of the weather, the probability of his ever arriving at a definite law would be far less than even in the before mentioned case of astronomy; for, though we are assured that the motion of every atom of air is governed by the same laws which direct the heavenly bodies, yet the amount of perturbation and reciprocal action presented in the case of myriads of atoms renders the probability of a com-

plete solution of the problem of the currents of the atmosphere, even with the greatest possible extension of human science, extremely doubtful. We must therefore be content with approximations deduced from general principles combined with the results of extended, precise, and definite observation.

The history of meteorology illustrates the fact, that what may be termed popular observations and experience, without scientific direction, seldom lead to important rules. The uneducated sailor of to-day, after three thousand years of experience, firmly believes that he can invoke the winds and entice them from the caves of Æolus by a whistle. Most of the aphorisms in reference to the changes of the weather, though of venerable antiquity, merely relate to the greater or less degree of moisture in the atmosphere. They declare what has happened, that a change has already taken place in the air, but give no certain indication of what is to occur. In order therefore to the successful study of meteorology, the results of *systematic* observations are to be compared with the deductions from well established principles of science, and the converse; or in other words, deduction and observation should constantly go hand in hand, the former directing the latter, and the latter correcting the conclusions of the former.

In meteorology, as in all other branches of science, the important rule adopted by Newton should never be neglected, namely: "No more causes are to be admitted for the explanation of any phenomenon, or class of phenomena, than are true and sufficient." Though a general principle which is in strict accordance with the established laws of force and motion cannot be immediately applied to the explanation of an isolated class of phenomena, it is not, on that account, to be set aside for some new and unknown agent. We must look to further investigations for the light which shall enable us to perceive the connection. The undulatory theory of light connects so many facts, and has enabled the scientist to predict so many others which were previously unknown, that though a few outstanding phenomena may still exist they do not militate against our convictions of the truth of

the generalization which this theory so admirably expresses; and we may safely attribute the apparent want of agreement to our ignorance of some essential condition of the phenomena in question, or to some error in the logical deduction from our principles. The history of science abounds in apparent exceptions to general rules which when better understood become additional evidences in support of the general principle. The foregoing remarks will not be thought inapplicable on the present occasion by those who have studied the history of the progress of meteorology.

One of the most important general truths at which science has arrived by a wide and cautious induction, and which is the foundation of meteorology, is that nearly all the changes which now take place at the surface of the earth are due to the action of the sun. The forces which pertain to the earth itself—such as gravity, chemical affinity, cohesion, electricity, magnetism, &c.—are forces of quiescence; they tend to bring matter to a state of rest at the surface of the globe, from which it is only again disturbed by the solar emanation. All the elementary substances which constitute the surface of our planet, with the exception of the organic matter, have long since gone into a state of permanent combination. The rocks and various strata are principally composed of burnt metals. The whole globe is an immense slag, analogous to that drawn from the smelting furnace, surrounded by a liquid and an aerial envelope; the former in a state of ultimate chemical combination, and the active principle of the latter—the oxygen—finding nothing to combine with, except what has been released from a former combination by the action of the sun. If therefore the solar impulses were suspended, all motion on the surface of the planet would cease: the wind would gradually die away; the currents of the ocean would slacken their pace, and finally come to rest; and stillness, silence, and death would hold universal reign. We cannot however at present pursue this thought, but must confine our remarks to the effects of those impulses of the sun denominated *heat* in their connection with meteorology.

All the phenomena referable to heat from the sun acting under varying conditions will now (so far as they affect the climate of the United States,) be considered under two heads:

1. The effects of varying astronomical conditions, irrespective of atmospheric and other influences.

2. The effect of all conditions, other than astronomical, such as the influence of the air, the ocean, the land, &c.

I. Results of Astronomical Conditions.

The earth, in its annual revolution in its orbit round the sun, does not describe a perfect circle, but an ellipse, of which the sun occupies one of the foci; and hence we are nearer at one season of the year to this central luminary than at another. It is well established by mathematical investigation from astronomical data, that at the present historical period, the earth as a whole receives the greatest amount of heat during any one day in the year on the first of January, and the least amount on the 4th of July. The variation in the distance of the sun produces no effect on the different seasons; since the rapidity of motion or the less duration of proximity to the sun, just compensates for the greater intensity of the rays due to the nearer approach. Were it not for this, the eccentricity of the orbit would materially influence the heat of the seasons, since the fluctuation in the heating power of the sun's rays on this account amounts to one-fifteenth of the whole; and it does in reality increase the diurnal intensity for a few days in January, as is shown from the ardor of the sun's rays under a clear sky at noon in the southern hemisphere. One-fifteenth, says Sir John Herschel, is too considerable a fraction of the whole intensity of sunshine, not to aggravate in a serious degree the sufferings of those who are exposed to it without shelter, in the thirsty deserts of the south. The accounts of what is endured in the interior of Australia at this season, for instance, are of the most frightful kind, and seem far to excel what have ever been experienced by travellers in any part of the northern hemisphere.

Another astronomical deduction is that the point of the

earth's orbit which approaches nearest the sun is constantly changing its place, and in time the order will be reversed; the greatest amount of heat from this cause will be on some day in July, and the least in January. But this change is so slow, that no appreciable effect has been produced during the historic period. A slight variation also takes place in the distance of the earth and sun when nearest to each other; but this also is confined to such narrow limits, that it is entirely insufficient to account for the changes undergone in the earth's temperature, as indicated by fossil plants and animals, and cannot, on account of its slowness, have had any appreciable effect upon the temperature of any part of the earth since the first records of civilized man. If therefore it be true, as some suppose, that the seasons have changed in different parts of the earth within the memory of man, the effect must be due to other than to astronomical causes.

The earth is approximately a sphere, and consequently, the sun's rays strike it obliquely at all places, except those over which it is precisely vertical. The amount of variation on this account can readily be calculated; the sun's beam may be considered as a force, and resolved into two parts, one of which is parallel to the surface of the earth, and the other perpendicular to it, the latter alone producing the result. The intensity of the sun's beam will be the greatest at the equator, and will gradually diminish to the poles. It is true the sun does not continually remain vertical at the equator, but the average result in the course of the year, is nearly the same as if this were the case; since the greater amount of heat received while he is at the north just compensates for the less while at the south. The average temperature of any given place, in consideration of the obliquity of the rays which the earth would receive if uninfluenced by other conditions, can be obtained by multiplying its equatorial temperature into the radius of its parallel of latitude; or (in more technical language) into the *cosine* of the latitude.

From this formula, which we owe to Sir David Brewster, we have calculated the following table, which exhibits the astronomical and observed temperatures of the valley of the

Mississippi, along a line passing through the city of New Orleans:

Lat.	Astron. mean temp.	Observed temp. reduced.	Difference.
25°	74·32	74·50	+ 0·18
30°	71·01	69·00	— 2·01
35°	67·17	62·00	— 5·17
40°	62·81	53·00	— 9·81
45°	57·98	44·50	—13·48
50°	52·70	37·00	—15·70

The temperature of the equator is assumed to be 82°. The first column gives the latitude, the second the astronomical mean temperature, the third the observed temperature reduced to the level of the sea, as taken from the accompanying isothermal chart,* and the fourth column the difference between the last two. It will be seen that the difference between the calculated and the observed temperature in the lower latitudes is quite small; but as the latitude increases, the deviation becomes very great. This difference is due to other than astronomical causes, and by eliminating the latter we narrow the field of research.

Empirical formulas of much nearer approximation to the truth in high latitudes have been proposed, which will be noticed hereafter, our object at present being only to exhibit the difference between the astronomical results and those derived from actual observation.

Let us next consider the changes of temperature in different parts of the day and in different seasons of the year, produced by the varying obliquity of the sun's rays. If we assume a given length of sun-beam as the representative of the force, and then resolve this into two,—one perpendicular, the other parallel to the horizon,—the sum of all the perpendicular lines, from the rising to the setting of the sun on any day, will represent the whole intensity of the heat on a given place during that day; and in this way may be calculated the relative amount of heat received on different latitudes at different seasons of the year. From this estimate we shall find that the amount of heat received from the sun during a given day in summer, say the 16th day of June, at dif-

* [See Map, at page 72.]

ferent northern latitudes, is greater than that which falls upon the equator during the same time. This is exhibited in the following table, from the paper of L. W. Meech on the sun's intensity, in the 9th volume of the Smithsonian Contributions, [page 18]:

The sun's diurnal intensity at every ten degrees of latitude in the northern hemisphere.

1853.	Lat. 0°.	Lat. 10°.	Lat. 20°.	Lat. 30°.	Lat. 40°.	Lat. 50°.	Lat. 60°.	Lat. 70°.	Lat. 80°.	Lat. 90°.
Jan. 1	77·1	67·2	55·8	42·8	30·1	16·5	5·1	----	----	----
Jan. 16	78·1	68·9	58·2	45·8	32·7	19·3	7·2	----	----	----
Jan. 31	79·6	71·7	61·9	49·7	38·6	25·0	11·9	1·4	----	----
Feb. 15	81·0	74·7	66·6	55·6	45·1	31·9	19·0	6·4	----	----
Mar. 2	81·6	78·0	71·3	62·9	52·7	41·1	27·9	14·5	2·1	----
Mar. 17	82·0	80·2	76·0	69·6	61·1	50·2	37·1	25·5	11·6	----
April 1	80·8	81·4	79·5	75·3	68·9	60·2	49·9	38·0	25·6	20·5
April 16	79·0	81·7	82·0	79·5	75·1	68·6	61·1	51·4	44·0	44·6
May 1	76·9	81·5	83·7	83·6	80·8	77·1	70·9	64·6	64 3	65·3
May 16	74·7	80·8	84·7	86·7	85·7	83·3	79·7	76·8	80·3	81·5
May 31	73·0	80·1	85·1	87·8	88·9	87·8	85·7	86·8	91·0	92·4
June 15	72·0	79·6	85·2	88·4	90·1	89·9	88·8	91·7	96·1	97·6
July 1	72·0	79·5	85·0	88·5	90·4	89·5	88·4	90·8	95·1	96·6
July 16	73·0	79·8	84·7	87·5	87·6	86·5	84·1	84·3	88·3	89·7
July 31	74·7	80·4	83·9	85·1	84·5	81·6	77·3	73·4	76·2	77·4
Aug. 15	76·7	80·8	82·7	82·4	79·8	74·7	68·2	60·9	59·2	60·1
Aug. 30	78·5	80·7	80·6	77·7	72·1	65·5	57·3	47·7	38·8	38·9
Sept. 14	79·8	79·8	77·5	72·6	65 6	58·8	46·9	34·5	21·9	14·7
Sept. 29	80·5	78·4	73·8	67·0	57·8	47·0	36·2	22·5	9·0	----
Oct. 14	80·7	76·4	69·7	61·0	50·2	38·2	25·7	12·6	1·0	----
Oct. 29	79·9	73·5	65·0	54·6	42·5	30·1	17·5	5·2	----	----
Nov. 13	78·8	70·7	60·8	49·8	37·1	23·8	11·0	0·9	----	----
Nov. 28	77·5	68·3	57·3	45·3	31·8	18·9	6·8	----	----	----
Dec. 13	76·9	66·9	55·4	43·0	30·3	16·3	4·9	----	----	----

On the fifteenth of June the sun is more than 23 degrees north of the equator, and therefore it might be readily inferred that the intensity of heat should be greater at this latitude than at the equator; but that it should continue to increase beyond this even to the pole, as indicated by the table, may not at first sight seem so clear. It will however be understood, when it is recollected that the table indicates the amount of heat received during the whole day;

and though in a more northern latitude the obliquity of the ray is greater, and on this account the intensity should be less, yet the longer duration of the day is more than sufficient to compensate this effect, and to produce the result exhibited. This is an important fact, in comparing the agricultural capacity of different latitudes; for though there is absolutely more heat at the latitude of New Orleans during the year than at Madison, in Wisconsin, yet there is more heat received at the latter place during the three months of midsummer than in the same time at the former place. An analogous but contrary result is exhibited in regard to the cold of winters, as will be seen by the table. It is from this principle that as we advance toward the equator, the extreme variations of the season become less and less. It is important to remark in this place that the foregoing tables exhibit the amount of heat actually falling upon the earth during the day as unmodified by any extraneous causes. They do not however exhibit the hottest portion of the season. This will depend upon another condition, which may be properly explained in this connection, though it is not classed under the astronomical causes. It is a well established principle that all bodies are radiating heat even while they are receiving it. If the amount received in a definite time is greater than that given off, the temperature will increase; on the contrary, if the amount given off is greater than that received, the temperature will diminish. The earth is constantly radiating heat into space, but only receiving it from the sun during the day. As the sun is declining towards the south, the daily amount received at length becomes less than that given off in the night, and hence the temperature begins to fall; and this diminution will continue until the two quantities again become equal, which will not be at the point where the greatest amount of heat is given off. On the twenty-first of June, in northern latitudes, the earth is receiving the greatest amount of heat, and hence it is becoming heated up most rapidly at this time. On the twenty-second it receives a less amount of heat, but the heating continues, since the gain is still greater than the loss; and this goes on until about the 25th of July, or

later, after which the radiation during the day and night together exceeds the amount received from the sun during the day, when the temperature begins to decline. The action is a little complicated, on account of the fact that the radiation increases with the temperature. A similar result is produced in the heating of the day, as will be seen from the following table of observations taken at every hour of the twenty-four, at Girard College, under the direction of Professor Bache:

MEAN DIURNAL VARIATION OF THE TEMPERATURE OF THE AIR AT PHILADELPHIA.

Computed from observations in 1842, and from July 1, 1843, to July 1, 1845.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	12 NOON.
48·2	47·8	47·3	46·8	46·6	47·0	48·1	50·1	52·1	54·1	55·7	56·8

Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
57·9	58·6	58·9	58·7	57·7	56·0	54·1	52·5	51·0	50·2	49·4	48·7

+
Maximum.

The result in the above table is somewhat affected by the greater humidity of the atmosphere towards morning, which prevents a greater radiation and fall of temperature, even after the rising of the sun.

II.—Results of other than Astronomical Conditions.

The deductions that have thus far been given are from established astronomical data; and unless some error has been committed in the statement, their correctness cannot be doubted by any person properly educated in the line of physical science. The effects produced by the air, the water, and the land, are however of a much more complicated character, and like the problem of the mutual action of all the planets on each other, have never yet been submitted to

a successful mathematical analysis. In the investigation of a phenomenon, it is not enough that we explain how it is produced; besides this, positive science requires that the explanation be true in measure as well as in mode, and indeed it is only when we can predict the exact amount of an effect, the principle being known and certain data given, that a phenomenon can be said to be perfectly analyzed. We have seen in the preceding paragraphs that the meteorological phenomena produced by astronomical causes admit of relative numerical expression; but in what follows we are obliged to content ourselves with the explanation in mode, and to refer to direct experiment and observation for the amount of the effect in measure. It is in this part of meteorology that so much uncertainty prevails, and in reference to which so much discussion, even of an excited character, has arisen. As was said before, the writer has no hypothesis of his own to advance and will therefore confine himself to a statement, and in some cases a brief examination, of such hypotheses relative to the effects of the atmosphere, the ocean, &c., in modifying climate as have been suggested, and which appear to be in accordance with established principles.

Effects of the Atmosphere in a Statical Condition.—Were it not for the aerial envelope which surrounds our earth, all parts of its surface would probably become as cold at night, by radiation into space, as the polar regions are during the six months' absence of the sun. The mode in which the atmosphere retains the heat and increases the temperature of the earth's surface may be illustrated by an experiment originally made by Saussure. This physicist lined a cubical wooden box with blackened cork, and, after placing within it a thermometer, closely covered it with a top of two panes of glass, separated from each other by a thin stratum of air. When this box was exposed to the perpendicular rays of the sun, the thermometer indicated a temperature within the box above that of boiling water. The same experiment was repeated at the Cape of Good Hope, by Sir John Herschel, with a similar result, which was however rendered more impressive by employing the heat thus accumulated in cooking the viands of a festive dinner.

The explanation of the result thus produced is not difficult when we understand that a body heated to different degrees of intensity, gives off rays of different quality. Thus if an iron ball be suspended in free space and heated to the temperature of boiling water it emits rays of dark heat, of little penetrating power, which are entirely intercepted by glass. As the body is heated to a higher degree, the penetrating power of the rays increases; and finally when the temperature of the ball reaches that of a glowing or white heat, it emits rays which readily penetrate glass and other transparent substances. The heat which comes from the sun consists principally of rays of high intensity and great penetrating power. They readily pass through glass, are absorbed by the blackened surface of the cork, and as this substance is a bad conductor of heat, its temperature is soon elevated, and it in turn radiates heat; but the rays which it gives off are of a different character from those which it receives. They are non-luminous, and have little penetrating power; they cannot pass through the glass, are retained within the box, and thus give rise to the accumulation of heat. The limit of the increase of temperature will be obtained when the radiation from the cork is of such an intensity that it can pass through the glass, and the cooling from this source becomes just equal to the heating from the sun. The atmosphere surrounding the earth produces a similar effect. It transmits the rays of the sun which heat the earth beneath; but this in turn emits rays which do not readily penetrate the air, thus effecting an accumulation of heat at the surface. The resistance of the transmission of heat of low intensity depends upon the quantity of vapor contained in the atmosphere, and perhaps also on the density of the air. The radiation of the earth therefore differs very much on different nights and in different localities. In very dry places, as for example in the African deserts and our own western plains, the heat of the day is excessive, and the night commensurably cool. Colonel Emory states in his Report of the Mexican Boundary Survey that in some cases on the arid plains there was a difference of 60° between the temperature of the day and that of the night. Indeed the air in this re-

gion is so permeable to heat, even of low intensities, that a very remarkable difference was observed on some occasions when the camp-ground was chosen in a gorge between two steep hills. The inter-radiation between the hills prevented in a measure the usual diminution of temperature, and the thermometer in such a position stood several degrees higher than on the open plain.

We shall next briefly consider the mechanical constitution of the atmosphere. The aerial ocean which surrounds the earth consists of atoms of matter self-repellant, which in proportion as the interior pressure is lessened, constantly tend to separate from each other and produce an enlargement or expansion of the whole mass. When the pressure is increased the mass sinks into a less volume, the atoms are brought nearer together, the force of repulsion is increased with the diminution of distance between the atoms, and a new equilibrium is attained. From this constitution of the air it immediately follows that the density of the atmosphere is greater near the surface of the earth than that at a higher altitude, since the lower stratum bears the weight of all those which are above it. The diminution in weight of equal bulks of air as we ascend is in a greater ratio than the height, since it diminishes on two accounts: first, because as we ascend in the air the number of strata pressing on us is less; and secondly, each succeeding stratum is lighter. From the law of this diminution of density a table may be formed of the pressure of the atmosphere at various heights, of which the following is an example:

Density of the air at increasing altitudes.

Miles above the sea.	Bulk of equal weight of air.	Density.	Height of barometer.
0	1	1	30·00
3·4	2	$\frac{1}{2}$	15·00
6·8	4	$\frac{1}{4}$	7·50
10·2	8	$\frac{1}{8}$	3·75
13·6	16	$\frac{1}{16}$	1·87
17·0	32	$\frac{1}{32}$	0·93

From this table it appears that one-half of the whole atmosphere is found within the upward limit of 3¾ miles, and one-third of the whole quantity beneath the average height of the Rocky Mountains: this fact has an important bearing on the influence of mountain ranges in modifying the direction of the winds.

The question occurs at this place, Why does the air grow colder as we ascend? The answer is that a pound of air, at all distances above the earth contains at least an equal amount of heat with the same weight taken at the surface, and that as the pressure is removed this air is expanded in bulk; consequently the heat is diffused through a greater amount of space, and hence the reduction of its intensity or temperature. To illustrate this, take a large ball of sponge and squeeze it into one quarter of the space which it naturally occupies; in this condition dip it into water, it will imbibe a certain quantity of the liquid, and when drawn out will be dripping wet; now let it expand to its natural dimensions, the water will be distributed through a large amount of space, and the sponge itself will appear comparatively dry. Squeeze it again into its former condensed state, and it will appear wet; suffer it again to expand, and the apparent dryness will be resumed. In a like manner we suppose that while the quantity of heat is the same, its intensity is increased by condensation into a smaller space and diminished by the converse process. In the foregoing illustration the amount of water contained in the sponge represents the amount of heat in the air, and the degree of wetness produced by condensation the intensity of the temperature exhibited in diminishing the bulk of air.

It follows from this that the blowing of a current of air over a high mountain, provided it descends again into the plain, does not necessarily diminish its temperature. When it arrives at the top of the mountain, it will become as cold as the circumambient air, not because it has lost any of its heat, but because that which it contained is now distributed through a greater space; when it descends again to the plain, it will suffer a corresponding diminution of bulk, on account

of the increased pressure, and with this the original temperature will be restored.

This principle, as we shall see hereafter, is of great importance in the study of the peculiarity of the temperature of the western portion of the territory of the United States. We have said that every pound of air, from the bottom of the aerial ocean to its surface above, contains at least an equal quantity of heat; and this was the inference of Dalton. From the investigations of Poisson and others it appears that the absolute quantity of heat, pound for pound, slightly increases rather than diminishes as we ascend; and this seems necessary to the stability of the equilibrium of the atmosphere as a whole. If the amount of heat were greater in the lower strata than in the upper, the equilibrium would be unstable, and an inversion would tend constantly to take place. An equal quantity of heat, (pound for pound,) as we ascend, would produce an indifferent equilibrium, while an increased amount in the order of ascent, would produce a stable condition of the atmosphere, such as that which really exists. The question however has not yet been fully settled, although it is an important one having a bearing on the explanation of many meteorological phenomena.

Another question of much interest is the exact law of diminution of temperature as we ascend into the air. Were this actually known, we could reduce to the same level all the observations which are made in a country; and thus, in addition to the astronomical effects, we could eliminate those due to altitude, and present the remainder as results which are due to the other conditions producing the peculiarities of climate. In order however to apply the law with precision in this way, it is desirable that it should be determined from observations made by ascents in balloons or at points of different heights on isolated mountain peaks. Relative observations made for this purpose on the top and at the base of mountain systems of considerable width and extent will probably give results involving the influence of the mountain surface itself, which in turn would be somewhat affected by the direction of the prevailing wind and

other causes. The progress of meteorology will call for an increased number of observations of the proper character, and for the repetition of the experiments with balloons, in different parts of the earth.

Celestial space, in which our sun and the earth and other planets of our system are placed, is known, from different considerations, to have a temperature of its own, which is supposed to be the result of the inter-radiation of all the suns and planets which exist in every part of the visible universe. The temperature of this space is estimated to be about — 60°. This fact being allowed, it will follow (since the heat at the top of the air remains constant) that the rate of decrease of temperature as we ascend will be diminished with the decrease of temperature at the surface of the earth, and also that the rate of decrease will follow a slightly diminishing ratio. At all accessible elevations in the atmosphere however it may be considered as almost constant. In some cases the rate of diminution is interfered with by abnormal variations of temperature; for example, as we ascend into the region of the clouds, the latent heat evolved in the condensation of the vapor produces a local heat in the atmosphere beyond the natural temperature. In temperate latitudes it is usual to allow 300 feet of elevation for the reduction of temperature one degree of Fahrenheit's scale. This quantity was deduced from thirty-eight observations collected by Ramond. Boussingault found, from observation in the tropics, the diminution at 335 feet. Col. Sykes, from mountain observations in India, the diminution at 332 feet. Saussure ascertained the mean value in the Alps to be 271 feet. Gay Lussac's celebrated voyage gave 335 feet. And the result of several series of observations with the balloon by Mr. Welch, under the direction of the British Association, omitting the points unduly heated by the condensation of vapor, was about 320 feet. In the construction of the isothermal chart * we have adopted 333 feet, or three degrees to one thousand feet, as the rate of diminution, and find in comparing the temperature of different places of varying heights

* [See Map, at page 72.]

which have been reduced by it, that they afford very satisfactory corresponding results. We propose to give a fuller discussion of this part of the subject in another report.

Motions of the Atmosphere.—The repulsion of the atoms of the air is not only increased by a diminution of distance from being pressed closer together, but also by an addition of heat. From the latest and most reliable experiments on this point it is found that the pressure being the same, air expands $\frac{1}{491}$ part of its bulk at the freezing point for each degree of Fahenheit's scale. Heated air therefore becomes specifically lighter, and tends constantly to ascend, being pressed upwards by the heavier circumambient fluid. The effect thus produced upon the air by the impulses from the sun is the great motive power which gives rise to all the currents of the atmosphere, from the gentle zephyr which slightly ripples the surface of the tranquil lake to the raging hurricane which overwhelms whole fleets, or destroys in a moment the hopes of the husbandman for an entire season. This fact is so well established by science that it is unnecessary to seek for any other *primum mobile* for the great system of constant agitation to which the aerial ocean is subjected.

Allowing the temperature of the equator, on an average, to be 82° F., that of the pole zero, and of the top of the air, or in other words, of celestial space, to be — 60°, and estimating the height of the atmosphere at 50 miles, it will follow from the law of expansion by heat, that the excess of elevation of the air at the equator will be upwards of four miles above that of the pole. Although this is not intended to present the exact amount of the aerostatic pressure, yet it will serve to show the great motive power constantly maintained by the influence of the solar radiation. In order to simplify the conception of the motions which result from this disturbing power, let us in the first place, suppose the earth to be at rest, and its whole surface of a uniform character, consisting, for example, of water. It is obvious from well established hydrostatic principles, that the air expanded as we have stated at the equator, would flow over at the top and descend, as it were, along an inclined plane towards the

poles, would sink to the earth, flow back to the equator below, and would again be elevated in an ascending current; and thus a perpetual circulation from either pole to the equator, and from the equator back towards the poles, along the several meridians of the globe, would be the continuous result. It is further evident that since the meridians of the earth converge, and the space between them constantly becomes less, all the air that rose at the equator would not flow along the upper surface entirely to the poles, but the greater portion would proceed north and south no further than the 30° of latitude; for the surface of the earth contained between the parallel of this degree and the equator is equal to that of half of the whole hemisphere. Portions however in the northern hemisphere, for example, would flow on to descend at different points further north; and of these some would probably reach the pole, there sink to the surface of the earth, and from that point diverge in all directions in the form of a northerly wind. Between the two ascending currents near the equator would be a region of calms or variable winds, influenced by local causes. The currents which flow over towards the poles would descend with the greatest velocity at the coldest point; because there the air would be most dense, or would have the greatest specific gravity.

According to the view here presented, a section of the atmosphere made by cutting through a meridian from pole to pole, perpendicular to the horizon, would exhibit two great systems of circulation; one from the north and another from the south to the equator below, rising at the latter place, and pouring over on either side to return again by longer or shorter circuits to the place whence they started. Such would be the simple circulation of the aerial ocean if no perturbing influences existed, and the whole science of meteorology would be one of comparatively great simplicity. But this is far from being the case. A number of modifying conditions must be introduced, which tend greatly to perplex the anticipation of results. First, the earth is not at rest, but in rapid motion on its axis from west to east.

Every particle therefore of the current of air as it flows towards the equator in the northern hemisphere would partake of the motion of the place at which it started, and in its progress southward it would reach in succession latitudes moving more rapidly than itself. It would thus as it were continually fall behind, and appear to describe on the surface of the earth a slightly curvilinear course towards the west. A similar result would be produced on the south side of the equator; and hence we have the first conception of the cause of the great systems of currents denominated the "trade winds," blowing constantly within the parallel of 30° from the northeast in the northern hemisphere, and from the southeast in the southern, towards the belt of the greatest rarefaction.

The motion however will require further consideration. The particles of air approaching the equator will not ascend in a perpendicular direction, as was first supposed, but as they rise will continually advance towards the west along an ascending plane, and will continue for a time their westerly motion in the northern hemisphere after they have commenced their return towards the north. They will however as they advance northward, arrive at parts of the earth moving so much less rapidly than themselves, that they will gradually curve around towards the east, and finally descend to the earth, to become again a part of the surface trade wind from the northeast. The particles will tend to move westward as they ascend: first, on account of their momentum in that direction; and secondly, because, as they reach a higher elevation, they will have less easterly velocity than the earth beneath. They will also be affected by another force, as has lately been shown by Mr. W. Ferrel, due to the increase of gravity which a particle of matter experiences in travelling in a direction opposite to that of the rotation of the earth. The last mentioned cause of deflection will operate also in a contrary direction on the atoms when they assume an easterly course.

The result of the complex conditions under which the motive power acts in such a case would be to produce a sys-

tem of circuits inclined to the west; the eastern portion of which would be at the surface, and the western at different elevations even to the top of the atmosphere. To give definiteness to the conception, let us suppose a series of books to be placed side by side on edge, pointing to the north; these books would represent the planes in which the currents of the air would circulate in the northern hemisphere, were the earth at rest; but if the earth is supposed to be in motion, then the books must be inclined to the west, so as to make an acute angle with the horizon, and overlap each other like the inclined strata in a geological model. If on each leaf of each book a circuit of arrows be drawn, then will the assemblage of these represent the paths of the different particles of the atmosphere. The currents of air however would not be in perfect planes, but in surfaces which could be represented by bending the leaves to suit the curvature of the earth. In this manner would be exhibited the general motion of the wind, which has been determined by actual observation.

The greater portion of the circulation would descend to the earth within 30 degrees of the equator, giving rise to the trade winds; a portion would flow further north, and produce the southwest winds; another portion would extend still further northward, descend towards the earth as a northwest wind, and so on. The air which descends in the region of the pole would not flow directly southward, but, on account of the rotation of the earth, would turn towards the west and become a northeasterly current. At first sight it might appear that the north wind which descends from the polar regions would continue its course along the surface until it joined the trade winds within the tropics; but this could not be the case, on account of the much greater western velocity this wind would require from the rapidly increasing rotary motion as we leave the pole. There would therefore be three distinct belts in each hemisphere, namely, the belt of easterly winds within the tropics, the belt of westerly in the temperate zone, and the belt of northwesterly at the north. The existence of these belts has been clearly

made out by Professor James H. Coffin in calculating the resultant of all the winds of the northern hemisphere, after having eliminated the effects of extraneous action, and thereby exhibiting the residue as the result produced by the general circulation.

Another condition however must be introduced. These belts would not be stationary, but would move laterally towards the south or the north, according to the varying positions of the sun at different seasons of the year. Their breadth would also vary; because they would be crowded into a smaller space towards the pole in the winter, and expanded into a wider space in the summer.

To trace with precision the path which would be described by a particle of air in its circuit, while under these varying perturbing influences, transcends the power of unaided logic, and could only be accomplished (if at all) by means of the most refined mathematical artifices. This problem has lately been presented (it is believed) as one of the prize questions of the French Academy of Sciences. Were it however solved with all the conditions that have been assigned, this would not be sufficient; since there is another cause of disturbance, perhaps more active than any yet enumerated, namely, the condensation of the vapor which arises from the surface of the ocean and is carried to different parts of the earth by the currents described. We owe to Mr. Espy, of this country, the principal development of the action of this agent in modifying and controlling atmospheric phenomena. The heated air which ascends at the equator is saturated with moisture, which it has absorbed in its passage over the northern and southern oceans. As it ascends above the surface of the earth it meets continually with a diminished temperature; and as the sun daily declines into the west, a considerable portion of it is converted into water which returns to the surface in the form of rain. The greatest effect of this action is immediately beneath the sun; and hence the belt of inter-tropical rains oscillates to the north and south with the course of the sun in its annual changes of declination. A portion however

of the same vapor is probably carried by the upper current far beyond the tropics, and deposited in fertilizing rains even at the extremities of the polar circles.

The condensation of the vapor which ascends in the equatorial regions evolves an astonishing power, in the form of heat, accelerating the upward motion of the air, and modifying in a greater degree than almost any of the causes we have heretofore mentioned, the primary motion due simply to the difference of heat between the poles and the equator. To understand this, it is sufficient to refer to the great amount of heat contained in a given amount of steam; and for illustration let us suppose the following simple experiment: A quantity of water at the temperature of melting ice is placed in a vessel over a lamp, which is so adjusted as to impart one degree of heat to the water in each minute of time. If the process is properly conducted, the heat will continue to increase, and, in accordance with the supposition we have made, the water at the end of about twelve hundred minutes will be all converted into vapor. If the process has been so conducted that a degree of heat has been given to the liquid in each minute of time, the steam will evidently contain about twelve hundred degrees of heat above the zero of Fahrenheit's scale. The greater portion of this will be in what is called a "latent" state; but it will all re-appear, as is well known from abundant experiments, when the vapor is re-converted into water. From these data it is easy to prove mathematically that every cubic foot of water which falls on the surface of the earth in the form of rain leaves in the air whence it descended sufficient heat to produce at least 6,000 cubic feet of expansion of the surrounding atmosphere beyond the space which the vapor itself occupied. The ascensional force evolved by this process must evidently be immense, when we consider the great amount of rain which falls within the tropics. A similar power is evolved whenever rain falls; and this principle, which has been so ably developed by Mr. Espy, is undoubtedly a true and sufficient cause of most of the violent and fitful agitations of the atmosphere which have so long puzzled the scientific

world. It however in its turn will probably require the consideration of modifying conditions in its applications; and while at present the data are known with sufficient precision to warrant the assumption of the evolution of the immense force we have mentioned, they are not in all cases sufficiently well determined to enable us to predict, with numerical accuracy, the results which have been shown to proceed from them. The same principle of condensation of vapor and evolution of heat is fertile in the explanation of the approximate cause of rain: for example, so long as the wind blows over a surface of uniform height and temperature, there is no cause to induce it to precipitate its vapor; but if in its course it should meet a mountain, the slope of which it is obliged to ascend, the vapor will be condensed on the windward side by the cold due to the increased vertical height. The latent heat will be evolved, the circumambient air will be abnormally heated, and an upward motion will ensue, towards which air will flow with increasing velocity to restore the equilibrium of the ascending column. In this way Mr. Espy explains very satisfactorily the fact that the wind blows over the desert of Sahara to supply the diminished pressure occasioned by the rains over the windward side of the Himalaya mountains. The same principle is immediately applicable to the explanation of the rainless districts in South America, Mexico, and other portions of the earth. The air, as it ascends on the windward side of the mountains, deposits its moisture; and if the elevation is sufficiently high, it will pass over in a desiccated condition.

The idea that mountains attract vapor is not founded on any well established principle of science. Molecular attraction extends only to imperceptible distances, and the attraction of gravitation is too feeble a force to produce results of this kind. The evaporation of water, and the transfer and subsequent condensation of the vapor in other parts of the earth, is undoubtedly the most active cause which produces the continual and apparently fitful changes of the weather.

We have stated that within the torrid zone there exists a

belt of rain, produced by the partial condensation of the vapor which ascends with the air of this region; and since the sun between the 21st of March and the 21st of June passes from the equator to 23½ degrees north, and then makes a similar excursion as far south, the rainy belt follows his course, and hence all countries within the tropics must have a periodical rainy season.

The air also which flows over to the north, and which, as we have seen, descends to the earth in the westerly belts of wind, carries with it a portion of vapor, and deposits it in the form of rain; and hence there is a tendency to a rainy and dry season beyond the tropics, which oscillates north and south with the varying motion of the sun. This tendency to regularity of rain is in many places masked or neutralized by the configuration of the country. It is however distinctly marked on the western coast of the United States and of Europe, as well as in various other places in the north temperate zone. Oregon and California have their rainy belt, which descends to the south in the winter, and again returns in the spring. In Lisbon, the number of rainy days in December is 15, to 2 in July; in Palermo, 17 in December, to 2½ in July. In Algiers, which is also north of the tropic, but farther south, from the average of ten years, there are 18 rainy days in January, and on the other hand, only a single one in July. Another fact of interest with regard to the extra-tropical belt of rain is that it commences sooner at greater elevations above the surface: for instance, at the peak of Teneriffe, the rainy season commences at the top a fortnight earlier than at the bottom; so that while rain is falling in abundance on the summit, the country in the vicinity of the mountain, at the level of the sea, is enjoying sunshine and a balmy atmosphere. According to Mr. Espy's views, the latter results from the radiant heat given off by the condensing vapor above. The sun however descending still farther to the south brings down the rain belt to the level of the earth in this latitude, and the rainy season then commences. Similar phenomena have been observed on the higher parts of the Coast range of mountains of California; and indications

of a like action are witnessed on the higher peaks of the Appalachian chain. Besides the causes of the general perturbations of the atmosphere, which we have thus given in considerable detail, some authors have added magnetism and electricity, and others have indeed attributed some of the principal effects we have mentioned to these agencies; but the present state of science does not warrant us in considering these as true or sufficient causes, except in the case of thunder storms, and perhaps tornadoes, in which the electricity evolved by the action of the storm itself may modify some of the results. Electricity however probably plays a subordinate part; since it is itself a consequence, and not a cause.

Terrestrial magnetism has not been shown in any case to affect meteorological phenomena; it is a force which never produces translation, but merely direction of the needle. The air in its natural condition is not magnetic in the proper sense of the term, any more than a piece of steel wire is so before the power has been developed in it by a magnet.

We are not allowed in strict scientific investigations, to explain a phenomenon by referring it to any agent, unless we show, in accordance with the laws of that agent, that it is capable of producing the result; and consequently magnetism is here not admissible.

Currents of the Ocean.—We have seen the effect of the unequal heating of different parts of the earth by the sun in giving rise to great gyrations of air; and it must be evident that there is a tendency to produce a similar result in the aqueous envelope of the globe. Let us first suppose the ocean to cover the whole earth to a uniform depth, and to be uninterrupted by continents. If the earth were at rest and the heat of the surface at the equator could extend down sufficiently into the depths of the water, the latter would be expanded and would stand higher in the equatorial regions than in those of the poles; a current therefore, as in the case of the air, would be established toward the north and south, from the equator, which would be cooled in its passage, would sink to the bottom, and return again to its

starting point, to commence the same course anew. If we now suppose the earth, as in the case of the atmosphere, to be put in motion around its axis towards the east, the bottom currents, or those flowing towards the equator, coming from a part of the earth moving slower to a part going faster, would fall behind, and thus assume a westerly direction. They would therefore ascend obliquely in a westerly direction towards the surface, flow back towards the pole, (in their course curving constantly towards the east,) and as they cooled would sink down towards the bottom, to return again to the equator. Different portions of the upper surface of the current, as in the case of air, would continue their northerly course obliquely, and descend at intervals, some reaching nearly to the poles.

The result of the whole of this action would be a series of gyrations to the north and south, with the upper portion turned towards the west, forming a continuous circuit at the equator round the whole earth in a westerly direction, and a circuit in each temperate zone from the west. This would be the result, if the water could be heated to a sufficient depth; and accordingly it is considered by some that heating the water is the principal cause of the currents of the ocean,—on which account I have so described it. Yet though doubtless a true—I do not consider it a sufficient—cause; but I would ascribe the currents of the ocean mainly to the action of the winds in the belts of the equator and in the two temperate zones.

The constant westerly winds on either side of the equator would tend to produce a westerly current around the earth, provided no obstructions existed to its free course; but if, instead of considering the earth as entirely covered with water, we suppose the existence of two continents, extending from north to south, forming barriers across the current we have described, and establishing two separate oceans, similar to the Atlantic and Pacific, then the continuous current to the west would be deflected right and left, or north and south, at the western shore of each ocean, and would form four immense circuits, namely, two in the Atlantic,

one north and the other south of the equator, and two in the Pacific, similar in situation and analogous in direction of motion. For a like reason there will be a tendency to produce a similar whirl in the Indian ocean, the current from the east being deflected down the coast of Africa, and returning again into itself along a southern latitude on the western side of Australia. Besides these great circulating streams, the water supplied by all the rivers emptying into the Arctic basin, as well as that from all the precipitation in this region, returns to the south, and by the motion of the earth must tend westwardly in a current along the eastern shore of each continent between it and the stream flowing to the north. Similar currents, but more diffuse and less in amount, must constantly flow from the Antarctic regions.

We do not mean to assert that these whirls can be continuously traced on the surface of the ocean, though by attentively examining the maps their general outline may be marked out. We wish to convey an idea of the general tendency of the motions of the aqueous covering of the globe—the central thought, as it were, on which they depend. The regularity of their outline will be disturbed by the configuration of the deflecting coasts and the form of the bottom of the sea, as well as by islands, irregular winds, difference of temperature, and above all, by the annual motion of the sun as it changes its declination. The effect of these currents in modifying the climate of different parts of the world has long been recognized, though the detail of the mode in which this is produced has not until recently been pointed out. The Gulf Stream of the North Atlantic carries the warm water of the equator beyond Iceland and the northern extremity of Europe, and it may even be traced to the shores of Nova Zembla. Without its influence the climate of Norway, Great Britain, and the western coast of Europe would be as cold as that of the corresponding parallels of latitude on the North American continent. In like manner, the great circuit of the waters of the Pacific conveys the warmth of the equator along the eastern coast of Asia to Kamtchatka, and gradually cooling in its course, descends

along the northwest coast of the North American continent, to receive a new accession of heat and be again conveyed to the north. The total result of this circulation together with those of lesser influence in the northern hemisphere, is shown in the annexed polar projection, in which the series of irregular lines, marked 50°, 32°, 16°, and 0°, indicate the mean annual temperature of the points through which they pass, and are called the yearly isothermal lines, or lines of equal heat.

The darker line, marked 32°, indicates the boundary of the region within which the average temperature is below the freezing point. It will be seen at a glance that, instead of being circular in its outline, it has the form of an irregular elongated ellipse, the greater diameter of which is across the pole, from the southern extremity of Hudson's Bay to

the south of Lake Baikal, in Siberia. It extends some degrees lower to the south in Asia than in America. The shorter diameter of the ellipse is at right angles to the longer, and passes from near Behring's Straits, through the pole, to the open ocean west of Norway. Its longer diameter is nearly twice that of its shorter, and is in the direction of the greatest amount of land in the polar regions. This form of the curve and the peculiarities of the other curves are due principally to the currents of the Atlantic and Pacific oceans transporting the water from the equator to the north, and carrying with it the higher temperature. An elliptical dotted line will be perceived in the polar regions, the centre of which does not coincide with the geometrical axis of the earth, but is nearer the continent of North America than that of Asia, thus indicating that the coldest point on the earth's surface is a number of degrees south of the pole. It is true, this region has never been visited by man; yet knowing the law of the diminution of heat, and the form of the other lines, the smaller one can be drawn with considerable accuracy. It may be interesting to remark in this place that the mean temperature of the coldest part of the northern hemisphere has almost exactly the temperature of the zero of Fahrenheit's scale; a somewhat curious although entirely accidental co-incidence.

We have thus far almost exclusively confined our remarks to the general principles of science on which the phenomena of meteorology depend; we shall now give special attention to the application of these principles to the peculiarities of the climate of the continent of North America, and more particularly to that part of it which includes the territory of the United States. For this purpose it will be necessary to give a brief sketch of the topography and surface of the country.

Physical Geography of the United States.—The climate of a district is materially affected by the position and physical geography of the country to which it belongs. Indeed, when the latitude, longitude, and height of a place above the sea, are given, and its position relative to mountain ranges and the ocean is known, an approximate estimate may be

formed as to its climate. The North American continent extends across nearly the whole breadth of the nominal temperate zone, and has an average width of more than fifty degrees of longitude. The general direction of the eastern coast of the United States lies in a great circle passing through Great Britian. Hence, a ship, while sailing along this coast, is on its direct route to the British Isles. This fact—which is not clearly exhibited on the flat surface of a map, but is shown on the convex surface of a globe—has a bearing, not only on commerce, but also on the direction of the Gulf Stream, which conforms to the general direction and sinuosities of the coast. It will be seen by the map,* (to which frequent reference is here made), that the eastern coast of the United States exhibits three great concave curvatures; the first commencing at the extremity of Florida, and extending to Cape Hatteras; the second, from Cape Hatteras to Cape Cod; and the third, from Cape Cod to Cape Sable. These broad ocean bulgings, or bays, have a marked influence on the cold polar current which descends along the coast, and also, as has been shown by Professor Bache, on the great tide-wave of the Atlantic ocean, as it approaches our shore. At the southern extremity of the United States is the great elliptical basin containing the perpetually heated waters of the Gulf of Mexico, an enormous steaming cauldron continually giving off an immense amount of vapor which, borne northward by the wind of the southwest, gives geniality of climate and abundant fertility to the eastern portion of our domain. On the western side of the continent the coast presents, as a whole, an outline of double curvature, principally convex to the west in that part which is occupied by the United States, and concave further north. These bends of the coast-line and of the adjacent parallel mountain ridges affect the direction of the winds in this quarter and consequently of the ocean currents. The Gulf of California at the south, between the high mountains of the peninsula of that name and those of the main land, must also materially modify the direction of the wind in that region.

* [See Map, at page 72.]

The continent of North America is traversed in a northerly and southerly direction by two extensive ranges of mountains—the Alleghany system on the east and the Rocky Mountain system on the west. We give the latter name to the whole upheaved plateau and all the ridges which are based upon it. These two systems separate from each other more widely as we pass northward, and between them is the broad interval which, within the territory of the United States, is denominated the valley of the Mississippi; but in reality the depression continues northward to Hudson's Bay, and even to the Arctic ocean, giving free scope to the winds which may descend from that inhospitable region. It however may be divided into two great basins, one sloping towards the south, comprising the basin of the Mississippi, and the other sloping to the north, including the basins of Mackenzie's river and of Hudson's Bay, the dividing swell which may be traced along the heads of the streams having an elevation of about 1,200 feet. Our remarks must be principally confined to the portion of the continent south of the 49th degree of latitude.

The swell of land or watershed, on which the Alleghanies are situated, has an average elevation of at least 3,000 feet, although the ridges and mountains based upon it rise to a much higher elevation. The loftiest point is Clingman's Peak, of the Black Mountains in North Carolina. It has lately been measured by Prof. Guyot, and is found to have a height of 6,702 feet. The next greatest elevation is Mount Washington, the highest peak of the White Mountains, in New Hampshire, which, according to the same authority, has an elevation of 6,285 feet. The lowest depression in this watershed, with the exceptions to be next mentioned, is in Pennsylvania, and has an elevation of a little less than 2,000 feet. Further north the whole system is cut through by the valley of the Hudson nearly to its base, and also by the valley of the St. Lawrence. The latter, together with the basins of Lakes Ontario and Erie, forms a narrow trough between the Atlantic and the Mississippi valley, along which the flow of air may locally affect the climate. The position

of the Alleghany Mountains however does not so much affect the meteorology of the country as from the magnitude of the system we might at first suppose; and this results from the fact that their direction is from the southwest towards the northeast, which as we shall see hereafter, is the prevailing direction of the fertilizing wind of the United States. They do not therefore obstruct its course; it flows on either side of them and along the valleys between them. They do however in a considerable degree, modify the character of the westerly winds as felt upon the coast, depriving them of their moisture.

A reference to the map will show that the Rocky Mountain system occupies one-third of the entire breadth of the United States, and that the remaining two-thirds are divided into two nearly equal portions by the Mississippi river, beginning at its source. This great western mountain system of the North American continent, which produces the most important modifying influence on the climate of the United States, may be described as a broad, elevated swell or plateau of land, (the prolongation of the system of South America, to which the Andes belong,) extending northward in the general direction of the Pacific coast, with varying elevation and width to the Arctic circle. It occupies nearly the whole breadth of Mexico, from the Rio del Norte to the Pacific, and becomes still broader as it extends northward, occupying at the latitude of 40°, (as has just been said,) one-third of the breadth of the whole continent. Resting upon this great swell of land is a series of approximately parallel ridges, the principal of which are the Rocky Mountain ranges on the east and the Coast ranges on the west, with ridges of less magnitude between, the general direction of which is north, inclining towards the west. Between these ranges is a series of extensive elevated valleys of extreme dryness, and, in the summer, of intense heat.

As we proceed north from the high plains of Mexico, the base of the system declines to about the 32d parallel of north latitude, where its transverse vertical section presents the least amount of land above the general level. It has how-

ever an average elevation in the principal part of about 4,000 feet, and the lowest notch or pass in the ridge on the eastern side is 5,717 feet above the ocean. Along the 35th parallel the vertical section across the mountain system is considerably greater in width and elevation. The general height above the ocean is at least 5,500 feet, and the lowest pass of the principal ridge is here 7,750 feet. The section of the system between the parallels of 38° and 40° has an elevation of 7,500 feet, and the lowest notch in the principal ridge is 10,032 feet above the level of the sea. From this section, as we pass to the north, the altitude and width decline; and along the parallel of about 47° the mountain base is much contracted in breadth, and has a general altitude of 2,500 feet. The lowest pass however of the most elevated ridge of this section is 6,044 feet. We have no definite information as to the mountain base north of this line. It appears however to continue at a lower elevation, and consequently to produce less influence upon the climate of the country to the east of it than the portion within the boundary of the United States.

From the eastern edge of what we have called the mountain system—that is from the foot of the Rocky Mountain chain to the Mississippi river—a space comprising, as was said before, about one-third of the whole breadth of the United States, the surface consists of an extended inclined plain, which slopes eastward to the Mississippi and southward to the Gulf of Mexico, having at the greatest elevation, near the intersection of the parallel of 40° and longitude 105°, a height of upwards of 5,000 feet, whence it gradually declines to the Mississippi river to about 1,000 feet. At the parallel of 35° it has very nearly the same elevation; and thence it slopes to the bed of the Mississippi to about 450 feet, and south to the level of the sea at the Gulf of Mexico. This extended plain is traversed by a number of approximately parallel rivers flowing eastward and southward to the Mississippi river and the Gulf of Mexico, which have their rise principally in the mountain system, and are chiefly supplied by the melting of the snow and the precipitation of vapor

which takes place at the summit of the ridges. The rivers are sunk deeply below the general surface of the plain, and give no indication of their existence from a distance, except the appearance of the tops of the cotton-wood trees which skirt their borders. The surface towards the southeast is slightly diversified by a low range of mountains, denominated the Ozark, which probably have some slight influence on the local climate of Kansas.

General Character of the Surface.—The general character of the soil between the Mississippi river and the Atlantic is that of great fertility, and as a whole, in its natural condition, with some exceptions at the west, is well supplied with timber. The portion also on the western side of the Mississippi as far as the 98th meridian, (including the States of Texas, Louisiana, Arkansas, Missouri, Iowa, and Minnesota, and portions of the Territories of Kansas and Nebraska,) is fertile, though abounding in prairies and subject occasionally to droughts. But the whole space to the west, between the 98th meridian and the Rocky Mountains, denominated the Great American Plains, is a barren waste, over which the eye may roam to the extent of the visible horizon with scarcely an object to break the monotony. From the Rocky Mountains to the Pacific, with the exception of the rich but narrow belt along the ocean, the country may also be considered, in comparison with other portions of the United States, a wilderness unfitted for the uses of the husbandman; although in some of the mountain valleys, as at Salt Lake, by means of irrigation a precarious supply of food may be obtained sufficient to sustain a considerable population, provided they can be induced to submit to privations from which American citizens generally would shrink. The portions of the mountain system further south are equally inhospitable, though they have been represented to be of a different character. In traversing this region whole days are frequently passed without meeting a rivulet or spring of water to slake the thirst of the weary traveller. Dr. Letherman, surgeon of the United States army, at Fort Defiance, describes the entire country along the parallel of 35°

as consisting of a series of mountain ridges, with a general direction north and south inclining to the west, and broken in many places by deep cracks, as it were, across the ridge, denominated cañons, which afford in some cases the only means of traversing the country, except with great labor and difficulty. The district inhabited by the Navajo Indians has had the reputation of being a good grazing country, and its fame has reached the eastern portions of the United States; but taking the region at large, it will be found that with regard to abundance of natural pasturage, it has been vastly over-rated, "and we have no hesitation in stating," says the same authority, "that were the flocks and herds now belonging to the Indians doubled, they could not be sustained. There is required for grazing and procuring hay for the consumption of animals at Fort Defiance, (garrisoned by two companies, one of which is partly mounted,) fifty square miles; and this is barely sufficient for the purpose." The barrenness and desolation so inseparably connected with immense masses of rocks and hills scantily supplied with water are here seen and felt in their fullest extent. Dr. Antisell, geologist to one of the exploring expeditions, describes the country along the parallels of 32° and 33° as equally deficient in the essentials of support for an ordinary civilized community. On the west, within these parallels, occurs the Great Colorado desert, extending to the river of the same name, which empties into the Gulf of California. From the southern portion of the Colorado river, which is generally regarded as the eastern edge of the Colorado basin, the land rises eastward by a series of easy grades until the summit of the main ridge of the mountain system is gained, at a point about 500 miles east of that river. For the first 250 miles the ascent is across a series of erupted hills of comparatively recent date, and similar in constitution to the line hills and ridges which are dotted over the various levels of the basin country. The entire district is bare of soil and vegetation, except a few varieties of cactus. Over the greater portion of the northern part of Sonora and the southern part of New Mexico sterility reigns supreme.

At the mountain bases may exist a few springs and wells, and in a few depressions of the general level of the surface sloping to the Pacific may be grassy spots; but such are the exceptions. A dry, parched, disintegrated sand and gravel is the usual soil, completely destitute of vegetable matter and not capable of retaining moisture. The winter rains which fall on the Pacific coast, west of the Coast range of mountains, do not reach to the region eastward. This is partly supplied with its moisture from the Gulf of California, but chiefly by the southeast wind from the Gulf of Mexico, flowing up between the ridges of mountains. We hazard nothing in saying that the mountains, as a whole, can be of little value as the theatre of civilized life in the present state of general science and practical agriculture. It is true that a considerable portion of the interior is comparatively little known from actual exploration; but its general character can be inferred from that which has been explored. As has been said before, it consists of an elevated swell of land covered with ridges running in a northerly direction inclining to the west. The western slopes, or those which face the ocean, are better supplied with moisture and contain more vegetation than the eastern slopes; and this increases as we approach the Pacific, along the coast of which, throughout the whole boundary of the United States to the Gulf of California, exists a border of land of delightful climate and of fertile soil varying from 50 to 200 miles in width. The transition however from this border to a parallel district in the interior is of the most marked and astonishing character. Starting from the sea-coast and leaving a temperature of 65°, we may, in the course of a single day's journey in some cases, reach an arid valley in which the thermometer in the shade marks a temperature of 110°. We have stated that the entire region west of the 98th degree of west longitude, with the exception of a small portion of western Texas and the narrow border along the Pacific, is a country of comparatively little value to the agriculturist; and perhaps it will astonish the reader if we direct his attention to the fact that this line, which passes southward

from Lake Winnipeg to the Gulf of Mexico, will divide the whole surface of the United States into two nearly equal parts. This statement, when fully appreciated, will serve to dissipate some of the dreams which have been considered as realities as to the destiny of the western part of the North American continent. Truth however transcends even the laudable feelings of pride of country; and in order properly to direct the policy of this great confederacy, it is necessary to be well acquainted with the theatre on which its future history is to be enacted and by whose character it will mainly be shaped.

Temperature.—Let us now consider the distribution of temperature of the wide belt across the continent of North America which forms the territory of the United States. To illustrate this, attention is requested to the lines drawn from east to west across the small map so frequently referred to. These it will be seen, are of three kinds: first, the full line, indicating the mean or average temperature of the year; second, the broken line, denoting the mean temperature of summer; and third, the dotted line, that of winter. These lines are drawn through portions of the earth's surface having equal temperatures for the periods mentioned, and are plotted from the result of numerous observations. They do not however in all cases exhibit the actual temperature of the surface; for in order to show their relations and render them comparable with each other and with similar lines in other parts of the world, it is necessary that the observed temperatures in elevated positions should be reduced to that of the level of the sea; and in the construction of this map allowance has consequently been made for decreasing temperature of one degree for every 333 feet of altitude. The map therefore will present to the eye the lines along which the temperature of the air would be equal for the periods mentioned, were we to suppose the mountain ranges entirely removed and the air brought down to the level of the ocean.

These lines, at a glance, exhibit remarkable curvatures, particularly in the western portion of the United States, indi-


Isothermal Lines.
Year.
Summer.
Winter.

cating a great increase of temperature in this region beyond that of the eastern and middle portion. Let us first consider the dark lines representing the mean temperature of the year. These, and indeed all the lines, are given for each ten degrees of Fahrenheit. Too much complication would be introduced were lines drawn for intermediate degrees on so small a map, though such lines have been projected on a larger one from which this has been reduced.

The first dark line, beginning at the top of the map, is that of the mean temperature of 40°. It commences near the northern part of Nova Scotia, passes through Canada and the middle of Lake Superior, slightly diverging from parallelism with the line of 45° of latitude until about the 95th meridian, when it more rapidly curves northward and leaves the United States for the British Possessions at about the 103d meridian, passing out at the top of the map at the 110th. The next line of mean temperature is that of 50°. It commences a little south of Nantucket, passes almost directly west, nearly parallel to the line of the 40th degree of north latitude, to about the 95th meridian of west longitude, whence it curves more rapidly to the north, meeting the coast of the Pacific in about the 48th degree of north latitude, near Puget's Sound. It thus exhibits the fact that the mean temperature of a point near Rhode Island is the same as that of a point on the Pacific, at least six degrees of latitude further north. The next line of mean temperature for the year, given on the map, is that of 60°; commencing near the mouth of Chesapeake Bay it inclines a little downward toward the 35th parallel of latitude until the meridian of about 98°, whence it rapidly ascends to the north, gains its greatest altitude at the 115th meridian, thence gradually declines southward to about the 125th, and thence, with a remarkably short bend, it passes parallel to the coast to about the latitude of 34°. By comparing the course of this line with that of the 35th parallel, it will be seen that the mean temperature is a little less near the Mississippi river than it is on the seaboard; but that in the great mountain system, in the same latitude as the mouth of the Chesapeake, the

temperature of a place is nearly equal to 70° instead of 60°, since the curve of 70° reaches almost as far north. The curve of the mean temperature of 60°, as has been stated, terminates on the shores of the Pacific, at about latitude 34°; whereas, on the Atlantic, it commences at about 37°, indicating a lower temperature along the 35th parallel of latitude on the Pacific than on the Atlantic shore. The next is the curve of 70°. This commences in about latitude 28° on the coast of Florida, passes through New Orleans, and thence to a point on the Pacific in the latitude of 30°. It presents an upward curvature in that portion which passes through the Gulf, indicating that New Orleans is warmer than a corresponding place on the Atlantic, or on the shores of Texas. It thence curves rapidly to the north, though indicating the greatest temperature near the eastern edge of the mountain system. It terminates on the Pacific at a point at least two degrees higher than its point of commencement on the Atlantic, thereby indicating that along the 30th parallel the mean temperature is a little greater on the east than on the west side of the continent. It should be constantly borne in mind, that the temperatures in these descriptions are those which would be exhibited were the mountain system of the country removed and the whole reduced to the level of the ocean. This system of lines therefore exhibits the extraordinary fact that eliminating the effect due to elevation, there remains a cause of a remarkable degree of abnormal heating beyond that due merely to the latitude of the place. In other words, that at every point within the mountain system, whatever may be its elevation, the temperature is far above that of the same elevation of a point in free space having the same latitude, when compared with the eastern and western coast.

The broken lines indicate the temperatures of summer. The first of these given on the map is that of 70° and commences near Long Island, ascends rapidly towards the north, and then descends towards the large lakes, passing through Lake Erie; it reaches its greatest northern declination at about the 110th meridian, and thence turning nearly paral-

lel to the coast, meets the Pacific in the latitude of about 34°. The portion of this curve along the coast of the Pacific shows the remarkable fact that the summer temperature is nearly the same from latitude 32° to 45°, or through a distance of 13 degrees, the whole having the same temperature as that of 41° on the Atlantic coast. This curve also clearly exhibits the great effect which the vicinity of the lakes has on the temperature of summer. While the dark lines indicating the mean temperatures of 40° and 50° are not at all affected by their proximity to these large bodies of water, the mean temperature of the summer is materially reduced. We may here call attention to the fact that the dotted line, denoting the winter, suddenly bends up at the same place, indicating an increase of temperature due to the vicinity of the same reservoirs of water. The line of 80° commences near Charleston, South Carolina, and extends rapidly upward through the valley of the Mississippi, thereby indicating that the temperature of summer in the interior, along this parallel, is much higher than on the seaboard. The western portion of this curve also exhibits great intensity of summer heat in the mountain system, and a remarkable degree of uniformity along the coast range of mountains parallel to the Pacific. The short lines of 82°·5 and 85° denote a high temperature of uniform intensity, extending to the north, and indicate the great summer heat of the western plain.

It will be seen, by examining the dotted lines, that the temperature of winter in the middle of the Mississippi valley, about the 95th meridian, is lower than on either the eastern or western coast; also, that the line of 30°, which is only two degrees below freezing, starts at the east end of Long Island, passes through Lake Erie, thence down to the 40th parallel, in longitude about 91°, and thence rapidly rises to the north, and leaves the United States at the 118th meridian. The line of 40° of winter temperature commences at the mouth of the Chesapeake, follows nearly the same general direction, and meets the Pacific Ocean near Puget's Sound, indicating the remarkable fact that this place and Norfolk, on the Atlantic, have about the same winter temperature. The line

of 50° is also similar to that of the last; also the line of 60°, which indicates in the Gulf of Mexico a lower degree of temperature in winter than exists on the Atlantic or Pacific coasts. In examining these winter lines attentively, it will be seen that the rise is not uniform from the 95th to the 105th degree, but the bend is most sudden about the 103d; which is probably caused by the occasional descent along this region of the polar winds to the Gulf of Mexico.

It has been stated that in reducing the lines to the level of the sea, 333 feet of elevation have been taken for each degree of Fahrenheit's scale. Therefore the actual temperature of any part of the United States may be readily determined, provided its elevation above the sea is known, by subtracting from the temperature given on the chart as many degrees as there are spaces of 333 feet in the elevation. Let us take, for example, the junction of the Kansas with the Missouri river, on the 95th meridian. This point, it will be seen by inspecting the map, is midway between the mean isothermal lines of 50° and 60°, and its temperature will therefore be approximately 55°. It has an elevation of about a thousand feet, which will give three degrees for the reduction; and hence its temperature will be about 52°.

On a little reflection it will be clear that it would have been impossible to draw these lines on the uneven surface of the earth. The variation of temperature due to height would mask that due to latitude and other climatological causes. For example, a greater elevation of mountain peaks at the south would represent a colder local temperature than regions further north, would entirely hide from view the results which are due exclusively to the peculiarities of conformation of the country, and would give no means of comparison.

Winds of North America.—We have said that the whole mountain system of the western portion of the United States presents a remarkable abnormal elevation of temperature above the eastern and middle portions of the continent, and the question naturally presses itself upon us as to the cause of this surprising difference. The simple statemant that the

western side of Europe is also warmer than the eastern side of Asia does not explain the phenomenon; it merely points out an analogy, but not a cause. It is evident that the position of the mountain system, and the direction of the ridges with reference to the prevailing winds, must have some connection with this phenomenon. In addition to this, the westerly aerial current, as it is principally derived from the equatorial regions, must in itself be warmer than the temperature due to the latitude of the belt in which it is moving. It will be well, therefore, before proceeding to this branch of the subject, to give a brief statement of some of the results which have been reached by deductions from actual observations in regard to this powerful agent in modifying climate. For the materials used for this purpose we are indebted to the valuable labors of Prof. James H. Coffin, of Lafayette College, the results of which have been published by the Smithsonian Institution.*

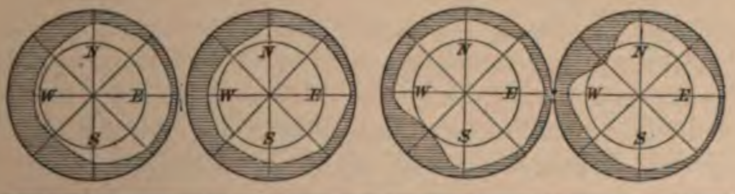
In order that the facts may be the more readily comprehended, and produce a more indelible impression upon the mind, since ideas received through the eye are the most definite and lasting, we shall represent the direction and amount of the wind by means of diagrams such as are exhibited in the accompanying figures. The lines indicated by the letters *N. E. S. W.* represent the cardinal points of the compass, and the breadth of shading along any of these lines the relative amount of wind in the course of a given period observed at a particular place.

Thus for example in No. 1, in the circle on the right hand

No. 1.

New York. *New England.*

Summer. Winter. Summer. Winter



*["The Winds of the Northern Hemisphere." 4to. 198 pp. 13 maps and plates. Smithsonian Contributions to Knowledge; vol. VI.]

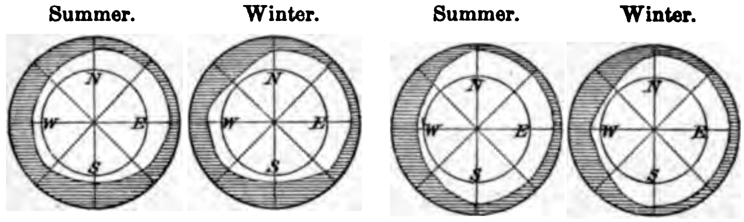
side, the shading represents the amount of wind from the different points of the horizon during the winter months in New England, from the average of a large number of observations at different places. Hence it will be seen that the predominant wind during the winter, in this part of the United States, is from the northwest; the next in amount is from the northeast and southwest, the eastern and southeastern portion of the horizon during the winter exhibiting but little wind. The next circle to the left shows the great preponderance of wind in New England from the southwest during the summer. The winds exhibited in the two circles combined will produce a general resultant from the west. The next circles to the left exhibit the amount of wind in summer and winter in the State of New York. In winter the greatest amount is from the northwest, and in summer from the southwest.

No. 2 presents the winds in Pennsylvania, and in Illinois, Wisconsin, and Iowa.

No. 2.

Illinois, Wisconsin, Iowa. *Pennsylvania.*

Summer. Winter. Summer. Winter.



From these it will be seen that in Pennsylvania the wind is more westerly in winter than in New England, but still the greatest amount is from a point north of west. In summer the greatest amount is found a little south of west. During winter in the States of Illinois, Wisconsin, and Iowa, generally, the greatest prevalence is from the northwest, and in summer from the west and south. The maximum is a little east of south; the southwestern half however of the horizon in both seasons has the greatest amount.

The circles in No. 3 indicate that in Nebraska and Kansas the greatest amount of wind in the winter is from the

northwest, and in the summer from the southwest. In Oregon and Washington Territories the greatest amount of

No. 3.

Oregon and Washington Territories. Summer. Winter. *Nebraska and Kansas Territories.* Summer. Winter.

wind in the winter is from the southeast, and the next greatest from the northwest, these two principally dividing the season between them. In summer a very large proportion is from the northwest, which is a remarkable inversion of the winds as observed in other parts of the United States. The principal current in winter being in the direction of the coast, from the southeast, consequently tends to mitigate the cold; while in summer it is in the opposite direction, and therefore tends to produce a similar effect in diminishing the intensity of the heat.

No. 4.

Texas and New Mexico. Summer. Winter. *S. C., Ga., Ala., Miss.* Summer. Winter.

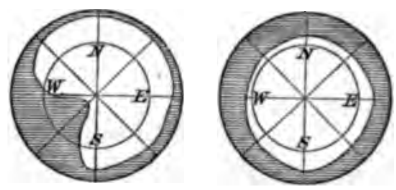
In No. 4 the two circles to the right exhibit the general direction of the wind in South Carolina, Georgia, Alabama, and Mississippi; and those on the left, in Texas and New Mexico. In the former the winds in winter nearly equally divide the whole circumference of the horizon; in summer the south and southeast winds prevail. In Texas and New Mexico the wind in the winter is largely from the north, and often

from the south; in summer its preponderance is greatly in favor of the south.

No. 5.

Lower California.

Summer. **Winter.**

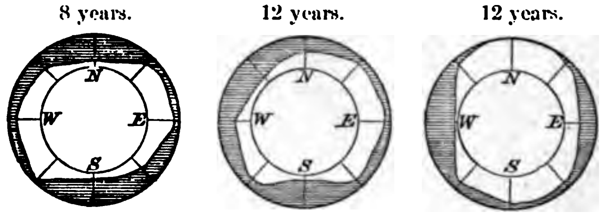


No. 5 exhibits the winds of Lower California, which in winter are from all parts of the horizon; those from the north and west however preponderating. In summer it is almost entirely from the southwest.

The winds thus represented are surface currents, and are consequently much influenced by the position of mountain ranges. This is strikingly shown in No 6, which represents the mean annual wind at Hudson, Albany, and Utica, in the State of New York.

No. 6.

Hudson, N. Y. 8 years. *Albany, N. Y.* 12 years. *Utica, N. Y.* 12 years.



Hudson is in the valley of the Hudson river, a long, narrow glen extending in a north and south direction; and as the figure indicates, the winds are principally confined to the same course, blowing down the glen to the south in winter, and in the opposite direction in the summer. Albany is situated at the junction of the wide Mohawk valley with that of the Hudson, and the wind accordingly is from the northwest and from the south. Utica is in the valley of the Mohawk, which has a general east and west direction, the

influence of which is strongly marked by the prevailing winds. In a like manner the direction of the wind on the coast of the Pacific is modified by the trend of the coast and the parallel mountain chains. Almost every position at which meteorological observations are made is liable thus to be affected by the local topography; but the result of this is eliminated in a great measure by computing the average direction from a number of stations within a limited distance of each other. Yet, though in this way the opposite local influences in particular districts may be made to balance each other, those of great mountain systems still remain. These in turn however may be merged in a series of observations extending across continents, or entirely around the world. In this way, by collecting all the reliable observations which have been made on the winds in the northern hemisphere, so far as they were accessible to the Smithsonian Institution, Prof. Coffin has established the fact, before mentioned, that the resultant motion of the surface atmosphere between latitude 32° and 58° in North America is from the west, the belt being twenty degrees wide, and the line of its greatest intensity in the latitude of about 45°. This however must oscillate north and south at different seasons of the year with the varying declination of the sun. South of this belt, in Georgia, Louisiana, &c., the country is influenced at certain periods of the year by the northeast trade winds, and north of the same belt by the polar winds, which on account of the rotation of the earth, tend to take a direction toward the west. It must be recollected that the westerly direction of this belt here spoken of is principally the resultant of southwesterly and northwesterly winds alternately predominating during the year.

From what has been stated in regard to the general circulation of the atmosphere it would appear that these winds are due to the returning upper currents which flow over from the heated region of the equator, producing a southwest, a west, or a northwest wind, according to the distance to which they extend northward before they commence to descend to the earth. If the sun continued on the equator during the

year, and there were no obstacles to the free motion of these currents, they would be constant in intensity and direction around the whole earth; but the change in declination of the sun, and the obstacles opposed by continents and mountain chains, modify in an important degree the simplicity of this motion. When the sun ascends to the north, it carries with it the whole circulating system of the atmosphere, causes the northeast trade winds to invade the southern part of the United States, and the inferior currents, which give rise to the southwest wind, to flow in summer over a large portion of our territory. The latter, charged with the vapor from the Atlantic and the Gulf of Mexico, impart warmth and fertility to all parts of the surface on which they descend. The higher currents, which produce the west and northwest winds, flow in summer above us, to descend further to the north. Their course however is marked by the almost invariable direction of the upper clouds and of the summer thunder storms, which, in the greater part of the United States, pass from the west to the east. The curving course of the returned currents, when the sun is south of the equator, is perhaps best marked by the direction of the hurricanes, which exactly follow the path we have described as that of the particles of air in the general circulation so often referred to. This will be seen by examining the storm tracks on one of the maps of the lamented Redfield.

It is evident, from theory as well as from every day observation, that the currents of the belt of the northern hemisphere, in which the United States is situated, must be subject to many perturbing influences, and that this region is well entitled to the denomination of the zone of variable winds. While the great circulation which we have described is going on, particularly above us, every rain that occurs and every variation of temperature tends to disturb its regularity at the surface of the earth. According to the views here presented the following winds of the United States belong to the general circulation, namely, the southwest, west, northwest, north, and northeast; while those from the opposite quarters of the horizon are principally due to abnormal

atmospheric disturbances. We say principally, because a portion of the surface northeast trade wind in summer probably blows over Florida and the lower part of Louisiana. These views have been strengthened by a series of observations collected by M. De Doue, from which it is shown that the winds from the western half of the horizon, as indicated by the clouds, preponderate over those from the east, as indicated by the wind vane at the surface; or in other words, that there is a greater tendency to a movement, even in our latitude, in the upper strata of air from the western half of the horizon, and in the lower from the eastern—a result in conformity with the general principles we have endeavored to explain. The circulation in the region of variable winds may often be inverted, and the compensation take place by means of winds in different parts of the hemisphere. It must be evident from mechanical principles that to balance every current of wind which flows to the north over any parallel of latitude along any meridian an equal amount must flow back to the south either along that meridian or some other. If the compensation takes place at the same meridian, one current must flow above and the other below. If at different meridians, the compensating currents may both be at the surface or both above. The fact that very different temperatures prevail at different parts of the world at the same time under the same latitude favors the idea of Prof. Dove that the compensation does in many cases take place in the latter way. Mr. Espy supposes that our southwest wind is produced mainly by the descent of the return trade winds at about the 30th parallel, and by rains accompanied with an elevation of temperature, and consequently an ascent of air at the parallel of 58° or 60°, and that it returns again in an upper current over the belt we have described towards the south. That whatever air reaches the polar regions should descend there and flow southward, and then rapidly decline to the west, appears to be an evident consequence of well established laws. The rapid inclination of the air on account of the great increase of rotation in the surface of the earth in this latitude would

tend to produce a wind in a westerly direction along the parallel of 60°, which would conflict with the currents from the south, and thus produce a low barometer—a tendency to rain—and form a natural boundary between what may be denominated the polar winds and the belt of westerly winds, due, as we have supposed, to the returning trades. The region of the middle belt must be one of great irregularity, occasionally encroached upon by the polar winds of the north on one side and the inter-tropical winds of the south on the other, tending to restore the equilibrium in some cases in the mode suggested by Prof. Dove, and again in that proposed by Mr. Espy. We are however inclined to believe that all these are perturbations in the general circulation.

That the great western mountain system of North and Central America produces an important effect on these currents cannot be doubted, when it is recollected that one-third of the whole atmosphere is below its higher portions. It prevents the northeast trade wind from passing to the coast of the Pacific in about the latitude of 30°, and probably deflects northeastward a part of the lower portion of the upper return wind, giving more force and quantity to the southwest summer currents than they would otherwise have. This is the view adopted by Mr. Robert Russell, of Scotland, one of the most industrious and promising of the younger meteorologists of Europe, who visited this country about three years ago for investigating its climate and agriculture. It would appear from what has been stated before, that a northwest current most generally prevails in the higher regions, and that the southwest current is a more superficial one. According to Mr. Russell, all the disturbances of the atmosphere in this country are produced by the unstable equilibrium occasioned by the superposition of the northwest wind on that of the southwest; and this, we think, in connection with the evolution of heat, according to the principles of Mr. Espy, will account for all the violent commotions of our atmosphere, whether they appear in the form of winter storms, thunder gusts, or tornadoes.

METEOROLOGY IN ITS CONNECTION WITH AGRICULTURE.

PART III.—TERRESTRIAL PHYSICS AND TEMPERATURE.

(Agricultural Report of Commissioner of Patents, for 1857, pp. 419–506.)

We intend in this number of our contributions to Meteorology as applied to Agriculture, to give a more definite exposition of some of the general principles of science especially applicable to this subject than is usually met with in elementary works. And we are lead to this by numerous inquiries from correspondents in various parts of our country, whose interest in the study of meteorology has been awakened during the last few years. We trust that our essay will be acceptable to the agriculturist, since however remote from his pursuits the theoretical part of the communication may at first sight appear, a proper view of the relation of science and art will enable him to see that the one is dependent on the other, and that each branch of the study of nature is intimately connected with every other.

We take it for granted that the American farmer is capable of logical reflection; that he is not content with the ability merely to perform with facility agricultural operations, and to direct with skill the ordinary routine of his farm; but that he is also desirous of knowing the rationale or scientific principles of all the processes he employs. We have no sympathy with the cant of the day with reference to "practical men," if by this term is understood those who act without reference to well-established general laws, and are merely guided by empirical rules or undigested experience. However rapidly and skilfully such a person may perform his task, and however useful he may be within the limited sphere of his experience and in the practice of rules given by others, he is incapable of making true progress. His attempts at improvement are generally not only failures, involving a loss of time, of labor, and of materials, but such as could readily have been predicted by any one having the requisite amount of scientific information. It is the due combination of theoretical knowledge with practical skill

which forms the most efficient and reliable character, and it should be the object of the agricultural colleges which are about being established in various parts of our country to produce educational results of this kind.

It is not expected that the farmer is to be a professional scientist, but that he should be familiar with the general principles of all branches of knowledge which more especially relate to his occupation; and the wider the extent of his information the better. Above all, he should be qualified to form a just appreciation of the value of original scientific investigations, and be ready at all times to adopt the principles which they may unfold, so far as they may be applicable to his uses; and moreover, be willing to render a due acknowledgment for the benefits thus conferred, and to contribute in any way in his power to the necessary, if not liberal, support of those who seek without the hope of pecuniary reward, to advance the bounds of human knowledge and of human power. The number of those in any age and in any country, who successfully investigate nature and discover new truths which form valuable contributions to the existing stock of knowledge, is comparatively small. The successful labor of the hands is much easier than that of the head; and therefore those who have actually proved by what they have done that they possess the ability to enlarge the field of science should be especially cared for, and their energies husbanded and directed to the one pursuit to which they may have devoted their attention. Unfortunately however there has always been in England and this country a tendency to undervalue the advantages of profound thought, and to regard with favor only those investigations which are immediately applicable to the wants of the present hour. But it should be recollected that the scientific principles which at one period appear of no practical value, and are far removed from popular appreciation, at a later time, in the further development of the subject, become the means of individual prosperity and national wealth.

About fifty years ago, Sir Humphry Davy moistened a

small quantity of ordinary potash, and submitting it to the current of a powerful galvanic battery, observed a number of brilliant particles burning and exploding on the surface. With the intuitive perception of a highly philosophical mind, he saw at once in this experiment a fact of the deepest significance,—the verification of a previous *a priori* hypothesis, namely, that potash and the other alkalies and alkaline earths were not simple substances, as they had previously been considered, but metals compounded with oxygen. This discovery, which had an important bearing on the whole science of chemistry but which had no interest for the popular mind, has in the course of time, revolutionized many of the processes of art, and will furnish the means, in various ways, of adding to the comforts and conveniences of life. Within the last two years a French chemist has discovered a process of decomposing one of these alkaline earths, (namely, the clay which forms the basis of the soil of the farmer, and which hardened by fire constitutes the brick to build his tenement,) and of obtaining from it a metal as light as glass, as malleable and ductile as copper, and as little liable to rust as silver.* These discoveries were made by men whose lives were devoted to the abstract study of nature; they were not the results of accident, but were logical deductions from previous conceptions of the mind verified and further developed by the ingenious processes of the laboratory. It may be safely said, that for every one individual who is capable of making discoveries of this kind, there are at least a thousand who can apply them to useful purposes in the arts, and who will be stimulated to undertake enterprises founded upon them by the more general and powerful incentive of pecuniary reward. When the process of procuring aluminum (or the metal from clay) shall have been perfected, and some enterprising citizen shall have established a great manufactory for the production of the article for general use, he will confer a benefit on his country, be entitled to credit, and will probably re-

* [Aluminum though first separated by Woehler in 1828, and more perfectly in 1845, was first made available by Deville in 1855.]

ceive the desired remuneration. But should the names of the chemists who originally made the discovery of the principles on which this public benefit depends be forgotten? Ought not their labors in enlarging the bounds of knowledge to be properly valued, and their names held in grateful remembrance? If living, should they not be afforded the means of extending their investigations, without the distraction of mind attendant on the efforts to obtain a precarious livelihood for themselves and families?

In truth we must say—not in the way of complaint, but for the purpose of drawing attention to the fact and with the hope of somewhat changing the condition of things in this respect—that in no civilized country of the world is less encouragement given for the pursuit of abstract science than in the United States. The General Government has no power under the Constitution to directly foster pursuits of this kind; and it is only by an enlightened public opinion, and the liberality of wealthy individuals, that a better condition of things can be hoped for.

The great facts of the future of agriculture are to be derived from the use of the microscope, the crucible, the balance, the galvanic battery, the polariscope, and the prism, and from the scientific generalizations which are deduced from these by the profound reflections of men who *think*, in contra-distinction to the efforts of those who *act*. The intelligent farmer should be able (as we have already said) properly to appreciate the value of scientific discoveries; and for this purpose his studies should not be confined merely to rules or empirical receipts, but should comprehend also the general principles on which they are founded.

Though some of the points we shall discuss in the following esssay may appear at first sight to be of too abstract a character to be comprehended by a casual reader, yet they will be found on attentive perusal, to be easily understood by a person of ordinary intelligence. But it may be well here to call attention to a fact frequently overlooked, that there is a great difference between *reading* and *study*, or between the indolent reception of knowledge without labor, and that

effort of mind which is always necessary in order to secure an important truth and make it fully our own.

Constitution of Matter.

Laws of force and motion.—All the objects which are presented to us in the material universe, and all the changes which we observe taking place continually among them, whether those which immediately surround us or those which we perceive at a distance, either by the naked eye or by means of a telescope, are referable to two principles—*matter* and *force*. By matter, we understand the substratum of that which affects our senses; and by force, that which produces the changes which we constantly observe in the former. The idea of force was probably first suggested to us by our muscular exertions: and indeed the original meaning of the term is a muscle or tendon; the Latin *vis* (force) being probably derived from the Greek *'is*, or *fis*. But we cannot imagine a force without some bodily substance by which, or against which it is exerted; the two ideas therefore of matter and force are co-existent in the mind, and on a clear and definite conception of them depends that precise relation of the phenomena of nature denominated *science*. Though the *essence* of force and matter may never be known to us, we can study the laws by which they are governed, and adopt such a conception of the constitution of matter as will enable us to generalize a vast number of facts; to connect these with each other, or with a central thought; to perceive their dependencies, and thus in some cases to control phenomena; to relieve the memory, and call into play the reasoning powers; and finally, to predict new facts, the existence of which had never yet been proved by actual experience. But such a generalization must be based on the well-established principles of the laws of force and motion, and be in strict accordance with accurately ascertained facts in the various branches of physical inquiry, in order that it may be an exact expression of the apparent cause of the phenomena, and that the prediction from it may be true in measure as well as in mode.

The laws of force and motion, to which we have alluded, may be expressed as follows:

LAWS OF FORCE.

1. Every particle of matter, at a sensible distance, attracts every other particle with a force varying inversely as the square of the distance. In the phenomena of electricity and magnetism, repulsion is also exhibited, acting in accordance with the same law.

2. Particles of matter at insensible distances, attract and repel each other with great energy, the attractions and repulsions appearing to alternate with minute changes of distance.

LAWS OF MOTION.

1. *The law of inertia.*—A body at rest tends to remain at rest, and when put in motion by the application of any force tends to move forever in a straight line with a uniform velocity.

2. *The law of the co-existence of motions.*—A body impelled at the same moment by several forces in different directions, will at the end of a given time be in the same position as if the forces had each acted separately.

3. *The law of action and re-action.*—When a force acts between two bodies of different masses, their momenta will be equal and opposite.

These laws were first given to the world in a definite form by Sir Isaac Newton in his *Principia.* They are ultimate facts of science, of which no satisfactory explanation is given; but by adopting them, as we do the axioms of geometry, and reasoning downward from them, all the great truths of modern astronomy have been evolved, as well as many of the facts of the molecular action of bodies.

Atomic Theory.

In connection with the laws of the forces and motion of matter, given above, we shall venture in this essay to express some of the widest generalizations of the present day in the form of what is called the *atomic theory.* This was the original conception of an imaginative Greek philosopher,

but in his mind it did not take that definite character which it has since assumed under the influence of inductive science. It was with him the vague and indefinite product of the imagination, unconditioned by the actual phenomena of Nature. It was adopted by Newton, who employed it with much success in the different branches of his investigations; but in modern times it owes its greatest development and range of application, to Dr. John Dalton, of Manchester, England, and still later principally to Mr. James Joule and Professor William Thomson. By means of it we are enabled to present in a single line a series of facts which could not otherwise be expressed in many pages, and also to exhibit to the mind the connection of a series of phenomena which could not, without this aid, be definitely conceived. It is intimately connected with all branches of physical science, and (strange as it may appear) particularly with agriculture; and we may therefore be excused for presenting it in its broadest applications, and with considerable detail.

According to this theory every portion of the whole universe, or at least that part of it which is accessible to us by means of the telescope, is occupied by atoms inconceivably minute, hard, and unchangeable, definitely separated from each other by attraction and repulsion. This assemblage of atoms constitutes the substance of the material universe; and to their attractions and repulsions, the forces by which they are actuated, is referable all the power or energy which produces the changes to which matter is subjected.

These atoms, thus endowed, form a plenum throughout all space, constituting what is called the ætherial medium, and in it, at wide intervals from each other, are isolated masses of grosser matter, which constitute our world, the planets, the sun, and stars. These also consist of atoms of another order, or of groups of atoms, with spaces between them, wide in comparison with the size of the atoms, which spaces are pervaded by the minuter atoms of the ætherial medium. These bodies move in the medium without encountering any sensible resistance.

The various isolated bodies of the universe act upon each

other by means of the force of gravitation, and also by tremors or vibrations in this medium, radiating in every direction from each body as a centre.

The atoms of matter are thus separated by intervals; and before we proceed further it will be necessary to consider more particularly this separation. It must be recollected that the hypothesis we are presenting is not the mere creature of the imagination, but is based upon a generalization of actual observation on the different states of grosser matter. We shall therefore commence with the consideration (as an example) of the constitution of the air. This we assume to consist of atoms, each endowed with attracting and repelling forces. That these atoms are not in contact with each other, will be evident from the fact that if we apply a sufficient pressure to a quantity of air taken at its greatest known rarity, it may be compressed into at least one ten-thousandth part of its primitive volume. The sum of the magnitudes of the void spaces is therefore, in this case, at least ten thousand times greater than the sum of the material parts, whatever be their nature. In order to explain this we are obliged to suppose that each atom is endowed with a repulsive force similar to that possessed by one pole of a magnet for a similar pole of another magnet. And this repulsion increases with the diminution of distance between the atoms. It is feeble when the volume of air is expanded to its fullest extent, and exceedingly powerful when highly compressed. Whatever weight we may put on the top of a piston fitted to a cylinder filled with air will be sustained by the repulsion of the atoms. The piston will descend until each atom is brought precisely to that state of proximity to the next that the repulsive energy between the atoms just balances the weight on the piston, and thus the most delicate equipoise is afforded by the air. The slightest extraneous force is sufficient to disturb the equilibrium, which is again restored by a series of decreasing oscillations.

If the atoms of the air however are removed to a much greater distance, the repulsion entirely ceases, and attraction of gravitation takes its place. If it were not for this, the

atmosphere would fly from the earth by the repulsive energy of its own atoms. We may therefore consider every atom of matter endowed with the property of obedience to the laws of force and motion; with inertia, by which it cannot change its place without the application of force, and when in motion cannot stop this motion without the application of an equal force in the opposite direction; and with attraction and repulsion, by which any two atoms placed at ever so great a distance from each other, will tend to approach each other with a force increasing inversely as the square of the distance. When these atoms approach very near to each other they cease their motion, and if pressed nearer than this point repel each other. And it appears from experiment and observation that there are several alternations of attraction and repulsion at distances too minute however for our senses, and only indicated by certain phenomena. Repulsion exists between the atoms of the densest bodies. Platinum, for example, which is 21 times heavier than water, and 257,000 times heavier than hydrogen, is still condensable. It may be compressed into a smaller space; and since the shrinking takes place equally in all directions, it follows that the atoms of this substance, as well as those of all gross matter, are not in contact. Indeed, when the hardest bodies are violently impelled against each other, and each is indented by the other, they do not come into actual mathematical contact, but are mutually impressed by the repulsive energy, which, vastly increased by the diminished distance, produces the visible effect.

All matter therefore is porous, whether in the gaseous, liquid, or solid condition. The pores may be conceived to be of different orders, namely, pores between the atoms, between the molecules or assemblages of atoms, and between the still larger particles. Gold itself is rendered brittle by being exposed to the fumes of sulphur, and solid iron is converted into steel by absorbing a large quantity of carbon, to which inter-penetration it owes its quality of hardness.

In the case of atmospheric air and other gases the repulsive energy alone is exhibited in most of the mechanical phe-

nomena, while in solid bodies both the attractive and repulsive are evident. Thus, if we place a heavy weight on the top of a vertical iron bar its length will be infinitesimally diminished. If the weight be removed, the atoms, by repulsion, will spring back to their original distances, and this may be repeated any number of times with the same result, provided the weight is not so great as to cause any permanent change which consists in a new arrangement of the atoms. If we now suspend the bar from one end, and apply a weight to the other, the bar will be minutely elongated; and if the weight be removed, the atoms, by their attraction, will return to their normal position. In this state the atoms are at the distance which constitutes a neutral condition. If pushed together, they fly apart whenever the compressing force is removed; and if drawn in the direction of the length of the body, they are brought into the region of attraction, and tend to bring the bar back to its original length when the elongating force is remitted.

This constitution of matter may be represented by a series of balls separated from each other by helical springs. If we attempt to elongate this bar the springs will be drawn out. When we attempt to compress the mass the several spires of the springs will be compressed closer together, and an action similar to repulsion will be produced.

This repulsion of the atoms is further demonstrated by the elasticity of a body, or the force with which it tends to restore itself to its former condition when disturbed by any extraneous force. The elasticity for instance of a rod of tempered steel is exhibited when we bend it. It tends to return to its first form in obedience to two forces. The atoms on the convex side, after the rod has been bent, are slightly separated, and are therefore in the region of attraction, while those on the concave side are brought nearer, and thus tend to repel each other. If this be the case, there should be a line somewhere near the middle of the bent rod, in which the atoms are neither compressed nor distended; and that such a neutral line does really exist can be shown by polarized light, which enables us, when the experiment is made on a

rod of transparent glass, to look into the interior of the elastic body and observe the changes there produced.

The difference between the compressibility of air and of steel depends upon the difference in the repulsion of the atoms in the two cases. But in the latter, as well as in the former, there is the most delicate balance of forces; for though a bar of good steel resists the weight of 60,000 pounds to the square inch tending to separate it in the direction of its length, yet the atoms may be thrown into vibration by the minutest force; and this is the case with all solids. A single tap with the end of a penknife on the table of the large lecture room of the Smithsonian Institution is sufficient not only to throw into vibration every particle of air in the room, but also every particle of the solid parts of the edifice. The agitation of the air is proved by the sound, discernible in every part of the room, and the vibrations of the solid parts also by the transmission of sonorous waves with even less loss than in the air.

The repulsion of which we have spoken, and which takes place only at minute distances, though these may be exceedingly great when measured by the size of the atoms, appears to be an essential endowment of matter, and is exhibited as well between the atoms of the ætherial medium as between those of air and other grosser assemblages of matter.

All bodies (as a general rule) are enlarged by an increase of temperature. But this result, as we shall endeavor to show, is not from an increase of the original repulsion, but from an energetic vibration imparted to the atoms, which tends to separate them and produce the phenomena improperly ascribed to an imaginary fluid called heat.

The medium of radiation.—We are obliged to assign to the ætherial medium a similar constitution to that possessed by grosser matter; namely, that it consists of inert atoms at great distances from each other relative to their own size, and each kept in position by attracting and repelling forces. Through this medium impulses or minute agitations are transmitted in celestial space, from planet to planet, and from system to system, which tremors or waves constitute light,

heat, and other emanations received by us from the sun. That is to say, the solar emanations are not matter, but motion communicated from atom to atom, beginning at the luminous body and diffused in widening spherical surfaces, enlarging in size and diminishing in intensity to the farthest conceivable portion of space.

The atoms of the ætherial medium are assumed to be perfectly free to move in all directions so that the earth and denser bodies experience no retardation as yet measurable; though lighter bodies, such as comets, apparently exhibit an effect of this kind for the same reason that a flock of cotton is more retarded in falling through the air than a piece of lead. At first sight it might appear paradoxical that atoms, which are kept in position by powerful attraction and repulsion, should yet be perfectly movable among each other; but this condition is observed in liquid water, the particles of which, though they exhibit perfect mobility, yet repel and attract each other with immense force. This arises from the fact that every atom beneath the surface of a fluid is equally attracted and repelled on all sides by the surrounding atoms, and is therefore perfectly free to move. Not so however with the atoms at the surface, for they are attracted downwards without a counteracting force to attract them upwards, and hence great resistance is manifested when we attempt to separate them.

The author of this essay has shown from conclusive experiments that the attraction of water for water is as great as that of ice for ice,* and that the difference of the two conditions consists in the perfect mobility of the atoms in the former case, and not in the neutralization of cohesion, as is generally supposed. If we attempt to draw up from the surface of water a circular disc of metal, say of an inch in diameter, we shall see that the water will adhere and be supported several lines above the general surface. This adhesion, on account of the perfect mobility of the atoms, is due alone to the attraction of the atoms of the external film and not to those of the whole mass which is elevated. This experi-

[* Proceedings of American Philosophical Society. See *ante*, vol. I, p. 217.]

ment, which is frequently given in elementary books as a measure of the feeble attraction of water for itself, is improperly interpreted. It merely indicates the force of attraction of a single film of atoms around the perpendicular surface, and not of the whole column elevated. The difference then of liquidity and solidity principally consists in the mobility of the atoms.

The immobility of the atoms of solids probably depends on their being assembled in larger groups, forming crystals, tissues, fibres, &c., and when force is applied to separate them they all resist together. In breaking a piece of steel for instance by extension, all the parts throughout the cross section of the mass simultaneously resist separation, and hence the great tenacity and rigidity of this substance: and between this and pure water other substances may be found having intermediate consistencies.

We have said that the atoms of the ætherial medium pervade those of all other bodies, and this postulate is analogous to the inter-penetration of the particles of different substances between each other.

If a piece of copper plated with silver be heated to redness the latter metal will be absorbed into the former. Water absorbs a large portion of air, and between the atoms of the air itself there may exist an indefinite number of other gases. Melted silver poured into water gives out a large portion of oxygen, which it had previously absorbed from the air in its liquid state.

If we suppose solid bodies to be composed of a series of groups of atoms, the larger in succession formed from the smaller, the vacuity in all cases may far exceed the solidity.

Let us now consider more minutely the nature of the emanations from the sun, (light, heat, &c.,) in connection with the doctrine of atoms. And in order to this we shall make comparisons between the phenomena of light and heat, and those of sound, passing by analogy from the palpable and well-known cause of familiar phenomena to that which is apparently not as readily accessible to our investigations, but which when properly understood is equally

satisfactory in the explanation, prediction, and control of the phenomena.

Analogy of heat and sound.—If a heavy cannon be discharged at the distance of five or six miles, we shall see the flash almost instantaneously, and in about half a minute after the window will be violently agitated.

What is the cause of this agitation? No substance shot from the gun has reached us, for the same effect may be perceived on all sides. The simple and true explanation of the phenomenon is that the atoms of air just around the mouth of the piece were for an instant violently pressed outwards by the blast of powder; these atoms were pressed against the next layer, and these against the next, and so on until the impulse reached the distant window.

Each atom makes a short excursion or vibration, moving but little from its first position, and it is not therefore matter which proceeds from the cannon and produces the distant effect, but a propagation of motion from atom to atom.

The atoms are endued with inertia, and time is therefore required, even though immense force may be applied, to give them full motion. And again, the atoms are not in contact, but are kept at a distance by repulsion, which increases when the atoms are pressed nearer each other. Hence the second layer of atoms does not begin to move with full velocity at the precise moment when motion commences in the first.

The effect would be similar to that which would take place in a series of balls kept apart from each other by helical springs interposed. If a blow were given to the first ball, so as to drive it nearer to the second, the motion would not be instantaneously communicated; the second would resist a change of state, and would not move from its position until the spring was considerably bent. And in this way time would be required to propagate motion from the first ball to the second, from the second to the third, and so on throughout the series.

If a series of lighter balls were substituted for the first, the springs remaining the same, it is evident the motion would

be transmitted sooner, because the inertia would be in proportion to the weight of the balls. Hence sound is transmitted more rapidly in lighter than in heavier gases; in hydrogen its velocity is greater than in carbonic acid.

Again, we may suppose the stiffness of the springs to vary, or in other words, the repulsion between the atoms to become greater or smaller. If the springs become stiffer, then it is evident the motion will be transmitted sooner, for if the springs were infinitely rigid, or what is the same if a perfectly solid body were interposed between the balls, then the first ball could not move without at the same moment giving motion to the last. Hence if we increase the elasticity of a medium and at the same time diminish the size of its atoms any required velocity can be attained. Now though the flash is apparently perceived at the same instant at different places on the surface of the earth, yet we know from the most satisfactory evidence that this is really not the case, and that light and heat, as well as sound, require time for their propagation. Every impulse at the sun requires about eight minutes before it is felt at the distance of the earth.

The analogy between light and sound does not cease here; and to exhibit the resemblance still further, let us suppose a large bell placed in mid-air to be struck a single blow with a heavy hammer; we know that the lower rim of metal will be thrown into a state of vibration; it will be compressed into an elliptical form, the shorter axis in the direction of the blow. The elasticity will bring it back to its normal state, and will then carry it beyond in the other direction; and thus the part of the bell which is struck will continue to move backward and forward rapidly for a considerable time, which would be indefinitely prolonged were the experiment made in a perfect vacuum, and were no change produced in the atoms of the metal. In open air however the motion becomes feebler and feebler, and after a few minutes dies away and entirely ceases. The principal cause of this diminution is evidently the imparting of the motion of the metal to the immediately surrounding atoms of the air, and these to the next, and so on. It

is evident that at the moment the rim of the bell is going from the spectator, a tendency to a vacuum would be produced, and the atoms of the first layer of air will follow the metal by their elasticity, thus producing a rarefaction into which the atoms of the second layer of air will rush; and this will advance from layer to layer until it reaches the ear of the observer. But before it has got far on its way, the side of the bell will return, and will condense the air in contact with it, and send a positive impulse in the same direction with the first. These two impulses, travelling with equal velocities, and the one immediately succeeding the other, form an undulation.

The effect may be strikingly illustrated by water in a long trough. If a small block of wood of the width of the trough be suddenly drawn out of the liquid at one end of the trough the water in immediate contact with the block will flow in to fill the vacuum; the water next will flow into the space thus left, and so on, a hollow or negative wave will be propagated from one end of the trough to the other. If the same block be suddenly thrust down into the water, the effect will be as if a quantity of water had been suddenly added. The liquid will rise at the side of the block, and in its fall another wave will be elevated outside of it, and so on continually, a positive wave or one of elevation, will be transmitted to the farther extremity of the reservoir.

If the two motions of the block be made, one immediately succeeding the other, a compound wave or an undulation will be the result. The transfer in this case is again that of form and not of substance. The atoms of water remain in place, as will be evident by placing bits of wood on the surface; they will rise and fall, but will not advance as the wave passes. This is an illustration of an undulation, but not an exact representation of a sound wave, which consists in a slightly alternate backward and forward motion of each particle between the bell and the observer.

An undulation of sound therefore consists of two parts—a condensed and a rarefied part; and hence when two series of undulations of the same wave length follow each other at

a distance of half an undulation, they neutralize each other, the protuberance of the one undulation exactly filling as it were the hollow of the other; or to express it more accurately, the rarefied and condensed parts of the two waves will neutralize each other, and in this way silence may be produced by two intense sounds. From analogy therefore, if light also consists of waves, two series might be brought together, so as to produce darkness. Both these inferences are fully borne out by experiment.

If we observe the effect of the sound waves upon a distant object, (such for instance as a delicate membrane stretched over a hoop and strewed with sand,) we shall find that on sounding an instrument the sand will be violently agitated: and if the vibration is in unison with any of the strings of a neighboring piano, they will give forth an audible sound.

It may be well to stop one moment to inquire in what this unison consists. It is well known that a string of a given length performs all its vibrations in the same time. Now if the impulses from the sounding body reach a string of such a time of vibration that the effect of the second impulse may be added to that of the first, or while the string is moving in the same direction as that given it by the first impulse, then the sounding will take place, or the string will be aroused into a motion harmonious with that of the sounding body. But if the impulses are not timed exactly to the vibrations of the string, they will meet the latter in its forward as well as in its backward movement, and thus tend to neutralize the effects of each other.

In the case of light and heat, the luminous or heated body is supposed to be in the condition of the bell during its sounding. The ætherial medium is the analogue of the air, and the vibrations of the optic nerve that of the tympanum of the ear.

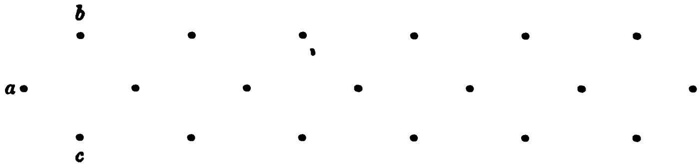
Further, in the case of heat, when the vibrations from the sun impinge upon the surfaces of solids and liquids, the ætherial medium within the interstices of these bodies, and also the atoms of gross matter, are put in a state of harmonious vibration, and thus give rise to the phenomena

of the heat of temperature or expansion. When, as we have previously indicated, the vibrations of the atoms of solids become sufficiently violent to throw them beyond the sphere of cohesion, the matter is converted from a solid into an aeriform condition.

But the question naturally arises, What is it that puts in vibration the luminous body (a candle, for instance) and keeps it for several hours in this constant state of agitation? The answer is, the continued rushing together of atom after atom of the carbon and hydrogen of the candle, and those of the oxygen of the surrounding air. An action of a somewhat similar kind, we must infer from analogy, is constantly producing impulses of a like character at the surface of the sun..

From the analogies of light, heat, and sound, we might infer, since there are different lengths of waves of the latter which give rise to the different notes of music, that there are different lengths of waves of the ætherial medium producing different sensations in us, and different effects upon gross matter. And this furnishes a ready explanation of the well-known phenomena of the different colors of the spectrum, and also of the less familar but equally remarkable phenomena of the different kinds of radiant heat, as well as of the chemical and phosphorogenic emanations from the sun.

That there may be different forms of waves transmitted through the same medium will be evident from inspecting the following figure, and considering the motions of the atoms which may be produced by a single impulse.



If we strike for example the atom a, it will be driven towards the second atom, and the second towards the third, the third towards the fourth, and so on; the motion will be transmitted along the central line of atoms to the other ex-

tremity. But while this motion takes place through the centre line of the assemblage of atoms, the motion of *a* will also bring it nearer to the atoms *b* and *c*, on either side; and these will therefore be repelled from their positions of quiescence, and lateral waves in which the atoms vibrate transversely to the direction of the ray, will be produced. It is probable that both kinds of vibration are transmitted through the ætherial medium, and perhaps both also through the air; but such is the constitution of our eyes that they can only perceive the results of those of the second kind, and such the constitution of our ears that they can only take cognizance of those of the first. The transverse vibration of light and heat was a happy conception of Dr. Thomas Young, (one of the discoverers of the key to the Egyptian hieroglyphics,) and was applied by himself and Fresnel to the explanation of a large and interesting series of facts classed under the name of polarization of light and heat.

Besides the invisible emanation from the sun, which gives us the sensation of heat, there are others equally invisible which produce other effects. Indeed it is possible that there are an indefinite number of waves, differing in length and perhaps in form, though many of these must be so minute as to produce no appreciable physical effect at the distance of our planet. If a beam of light be decomposed by a prism, it is well known that it will be separated into parts, producing different colors. Now if we subject to this spectrum a piece of paper which has been soaked in a solution of nitrate of silver, we shall find that the salt of silver will be decomposed, and the paper will be blackened by the reduced metal. But the interesting part of the experiment is that the blackening will be more intense at a point in the prolongation of the spectrum, which is entirely in the dark. There is then in a sunbeam, besides light and heat, a ray which may be separated from the former by a prism, which produces chemical decomposition, and is hence called the chemical ray. I need scarcely remark that it is this ray, and not that of light, which produces the picture in the photographic and daguerrean processes.

Again; it is well known that if we expose a diamond for an instant to the rays of the sun, and then convey it to a dark place, we shall see it glow with a pale phosphorescent light; but this effect, long familiar as it has been to the natural philosopher, is now known to be the result of an emanation differing in some essential particulars from all the other emanations which we have mentioned. To prove this, it is sufficient to place the diamond under a plate of transparent mica, a substance which transmits freely light, heat, and the chemical emanation. This will screen the diamond; and the glowing, which was before very striking, will not now be produced. That this effect is not the result of the absorption of a ray of light will be evident when we mention the fact that a diamond will glow when placed under a thick plate of smoky quartz, which intercepts both light and chemical emanation, but freely transmits what is denominated the phosphorogenic ray. These results are all in accordance, in a general way, with the constitution of the ætherial medium which we have presented.

Light and heat appear to differ only in the lengths of the waves, which become shorter and more intense as the temperature of the source of emanation increases; though in some cases, as in that of luminous phosphorus and the light of the glow worm, it is emitted freely from bodies of low temperature. It is possible that light from these different sources may possess different physical properties.

Electricity.—The phenomena of light, of heat, of the chemical and phosphorogenic emanations have all been referred to vibrations of the ætherial medium, and all the facts which have thus far been observed are in accordance with this generalization. The question however naturally arises as to what explanation we can give of the multiplied and various phenomena constantly presenting themselves to us in connection with the changes which are taking place around us in nature, or which exhibit themselves to the chemist and physicist in their investigations of the minuter re-actions which are brought about by their agency, and which are classed under the general name of electricity. It is a

recognized principle of philosophy to adopt no other causes for the explanation of phenomena than are true and sufficient; and although the existence of the æthерial medium may by some be doubted, yet to me it appears as certain as any fact can be which rests upon inferences drawn from observed phenomena. The wave motions which we refer to it, and which exactly agree with the observed facts, are precisely such as are produced in gross matter under the action of the laws of force and motion, and therefore we have nearly the same reason for believing in the existence of this diffused substance as in that of gross matter itself. Besides, the tendency of science is to reduce rather than increase the number of agencies to which effects are referred as causes. We shall therefore assume that the ætherial medium is also the agent by which the phenomena of electricity are produced, but the facts classed under the head of electricity cannot be explained on the principle of wave-motions, and we must therefore seek for some other probable mechanical action from which they may be rationally deduced.

Electrical phenomena may be referred to two great classes, statical and dynamical, or such as appear to be produced by the repulsive action of a fluid at rest, and by the same fluid in a state of motion. In some cases we have action at a distance on surrounding bodies which develop new and permanent properties so long as the conditions remain the same; and in other cases effects which exactly resemble those of a transfer—not of a property, but of actual substance, from one body to the other. Now these phenomena may be referred to an accumulation of the ætherial medium in one portion of space, and a corresponding diminution in the adjacent space. If the particles of the ætherial medium, when thus accumulated, act at a distance on other portions of the same medium we shall have a rational exposition of the phenomena of statical electricity; and in the restoration of the equilibrium of the medium, or in its return to its normal condition, we have a plausible cause of the dynamic effects belonging to the same class. But how is this disturbance of the equilibrium of the ætherial me-

dium produced? The answer is, by the agency of gross matter. From the refraction of light and the various effects of heat we must infer that the ætherial medium is intimately connected with gross matter; and although the latter may move in it without disturbing the equilibrium, yet when two pieces of gross matter are rubbed together an accumulation of the atoms of the ætherial medium may take place on the one and a deficiency on the other. According to this view there can be no electrical excitement in celestial space; for there gross matter does not exist, without which the medium cannot be coerced or the equilibrium disturbed. It is not supposed, in accordance with this hypothesis, that there is an absolute vacuum produced in the medium, but that a condensation exists in a given spot, and a corresponding rarefaction in the space around it. The degree of this condensation and rarefaction may be exceedingly slight in comparison with the whole elastic force of the medium, and therefore it is not essential to the truth of the hypothesis that any very perceptible changes should be produced in rays of light passing in close approximation to electrified bodies.

This hypothesis is adapted to the theory of either one or two fluids. In the second case the ætherial medium must be supposed to consist of two kinds of atoms, the separation of which gives rise to the phenomena observed; and in the first that it consists of but one kind of atom, and that the effects observed are due to its being in excess in one body, and in deficiency, at the same time, in another.

In a new investigation of the discharge of a Leyden jar, by the author of this essay, the facts clearly indicated the transfer of a fluid from the inside to the outside, and a rebound back and forward several times in succession, until the equilibrium was attained by a series of diminishing oscillations.

The magnetic phenomena may be referred to an assemblage of electrical currents, according to the theory of Ampère, or to a peculiar arrangement of the ætherial atoms within the magnetic body.

The electro-magnetic phenomena appear to be due to the action of the atoms of gross matter combined with that of the ætherial medium.

We cannot here go into an exposition of the facts of electricity and magnetism, but will merely point out one inference from the hypothesis we have given, namely that electricity is not in itself a primary source of motion or mechanical energy, tending to produce change by a kind of spontaneity, (as is frequently supposed,) but is the effect of a disturbance and subsequent restoration of an equilibrium, which disturbance has been produced by the application of an extraneous force. This conclusion may also be arrived at, without reference to the hypothesis, from the study of the facts themselves, which clearly demonstrate that the electrical equilibrium (whatever may be its nature) is never disturbed by its own action, but the manifestation is always the effect of the application of some other power, and is the mechanical equivalent of such disturbing cause.

Crystalline forms.—We will now consider the grouping of the atoms which is intimately connected with the various properties of different kinds of bodies. When the atoms of gross matter are suffered to approach each other, without disturbance or agitation, and from an aeriform or liquid condition to gradually assume the solid form, they exhibit beautiful geometrical figures, familiarly known under the name of crystals. For example if a quantity of common salt be dissolved in water and the liquid be suffered to evaporate in a still place, beautiful crystals of a cubical form will be found in the vessel; or if ordinary saltpetre be dissolved in warm water and suffered to cool, regular six-sided crystals will be obtained. If these crystals be reduced to an impalpable powder and again dissolved in hot water the same result will again be produced, provided the liquid be not in excess.

The most interesting illustration of crystallography to the meteorologist is that exhibited in snow and hoar frost. These generally consist of stellar figures in one plane, with rays and branches of rays, all making angles of 60° with

each other, and under different conditions of the atmosphere are exceedingly varied and beautiful. To explain these figures in a general way let us suppose three separate atoms to be within the sphere of mutual attraction and free to move; they will approach until they come within the sphere of repulsion, and will then evidently be found in the same plane at the angular points of an equilateral triangle, since each must be at the same distance from each of the other two. If a fourth atom be suffered to approach in the same manner it will also arrange itself at an equal distance from each of the three others at the apex of a regular triangular pyramid of equal and similar faces. The next symmetrical arrangement which could take place would be in case a fifth atom were added; and if this were situated on the other side of the base of the pyramid a regular six-sided figure would result. We see from these examples that regular geometrical forms are the necessary effect of the undisturbed grouping of the atoms, though it is impossible to deduce all the facts from considerations as simple as those we have given above. To adapt the hypothesis to the facts of the case we are obliged to assume that crystalline forms are not the result of the approximations of single atoms, but of molecules of more or less complicated structure.

Though the exact representation of the groupings of particles of different kinds of matter has exercised the ingenuity of a number of investigators, the theory is still in a very imperfect condition. It offers however a rich harvest for scientific culture, and a number of interesting conclusions have been deduced from the crystallographic study of bodies, particularly by M. Gaudin. We are obliged to suppose that the primary molecules which enter into crystals are themselves of a geometrical shape, due to the arrangement of the ultimate atoms of which they are composed, and such forms are called the primitive forms of the crystalline molecules. These primitive molecules vary in form and size, as we shall see hereafter, and they vary also in these respects, in some cases of their combinations. If the two salts we mentioned in the commencement of this division of our subject—namely,

saltpetre and common salt—be dissolved together in a sufficient quantity of water, and the liquid be suffered gradually to evaporate, they will be found at the bottom of the vessel in separate crystals. The cubes of common salt can readily be distinguished from the long-sided prisms of saltpetre, and when these are chemically analyzed, each is found to be exclusively composed of its respective substance. Not a single atom of the saltpetre is found in the crystal of salt, nor one of the latter in the former. The same effect takes place if magnesia and saltpetre be dissolved in hot water and the solution be suffered to cool. The case however is altogether different when sulphate of magnesia, and sulphate of nickel or sulphate of zinc are crystallized together, from the same solution. The separation of the two substances does not take place as in the former instance; the individual crystals formed will contain both sulphate of zinc and sulphate of magnesia, or sulphate of nickel and sulphate of magnesia, and this in every possible proportion, according to the relative amounts of the two salts in solution. Now if we compare a crystal of sulphate of magnesia with a crystal of sulphate of nickel, we find they have identically the same crystalline form: there is no perceptible difference in their angles, edges, or solid angles. And since a large crystal is built up of an aggregation of small ones of the same form, it is evident that the primitive molecule of sulphate of nickel must have the same form as that of the sulphate of magnesia; and therefore that in forming a large crystal they may be mingled together in the way we have just described, provided they are of the same size, or perhaps some multiple of the same size, for it is evident that it would be impossible to build a wall of symmetrical structure with bricks of different angular forms and sizes, since the parts would not fit or exactly fill the spaces. We must therefore conclude that though the ultimate atoms of bodies may be spherical, the groupings of them, which form the primitive crystallizing molecules, are of different geometrical shapes and sizes.

The atomic weights or combining proportions.—Though the primordial atoms may all be of the same weight and size,

and the different kinds of matter the result of the different forms in which they are grouped, yet in the present state of science there are sixty-one substances which are classed by the chemist as simple bodies, and which must continue thus to be classed until they shall be actually de-composed into two or more separate components. If these bodies consist of elementary atoms, or of groups of atoms, always of the same number and form, it will follow that all combinations of them will take place in definite and fixed proportions. For example, it is known that one part of hydrogen by weight unites with eight parts of oxygen to form water, and this liquid, whenever found, always contains the same proportion of these ingredients. But there is another compound of oxygen and hydrogen, of which the components are in the ratio of one to sixteen, and this result is precisely that which might have been anticipated from the theory of atomic combination. In the first case, if the atom of hydrogen weigh one, (for instance, one millionth of a grain,) and the atoms of oxygen eight, (eight millionths,) then any amount of combination will have the same proportion. The combinations then will be one to eight, one to sixteen, and if another combination of oxygen and hydrogen exist, it will be in the ratio of one to twenty-four. In the first instance, it is one atom to one; in the next, of one atom to two; in the third case, it would be one atom to three. This is also beautifully shown in the union of oxygen and nitrogen, of which there are five different compounds, as exhibited in the accompanying table.

Names of Compounds.	Weight.		Ratio.	
	N.	O.	N.	O.
Protoxide of nitrogen (nitrous oxide)	14	8	1	1
Binoxide of nitrogen (nitric oxide)	14	16	1	2
Hyponitrous acid	14	24	1	3
Nitrous acid	14	32	1	4
Nitric acid	14	40	1	5

A glance at this table will show the justice of the remark of M. Dumas, that granting matter to be atomic it must necessarily combine as it is found to do in this instance. We refer to any work on chemistry for a table of atomic weights, and shall only give here those of the atoms which form the principal part of animal and vegetable bodies, namely, hydrogen, carbon, oxygen, and nitrogen:

	Atomic weight.
Hydrogen	1
Carbon	6
Oxygen	8
Nitrogen	14

To these, in lesser quantities, are added sulphur, 16; phosphorus, 32. We may say therefore that the whole atomic system of animal and vegetable physiology depends principally on the four numbers 1, 6, 7, 8. Wherever the substances above mentioned are found in combination in any of the three kingdoms of nature, they always combine according to these numbers, or multiples of them—a statement which contains in a single line a truth of the widest significance; which has rendered chemistry an almost mathematical science, and its applications to agriculture an art of the highest value and yet of comparatively easy attainment. To facilitate still more the use of this generalization, the atoms are expressed in abbreviated language. Thus water is represented by HO—that is, one atom of hydrogen, 1, and one of oxygen, 8, making nine for the weight of the liquid. Two atoms of water would be represented by 2 HO; carbonic acid by CO_2, or one atom of carbon, 6, and two atoms of oxygen, 16; making for the atomic weight of the acid 22. Nitric acid is represented by NO_5, and ammonia by NH_3, and nitrate of ammonia by NO_5+NH_3; indicating, in the formation of nitric acid, five atoms of oxygen and one atom of nitrogen, and in that of ammonia, three atoms of hydrogen to one of nitrogen. The attainment of a knowledge of this notation is easy, while the use of it is exceedingly convenient.

Atomic volumes.—The spheres of repulsion of different chemical atoms, or rather molecules, are probably different;

and as we may consider these spheres as constituting the size of the atoms, in reference to the space which they occupy in combination, their magnitudes may be calculated with a view to ascertain whether any similarity can be found in the properties and action of bodies having equal atomic volumes. To explain how this may be done, let us suppose we wish to know the number of atoms in a given volume of matter of which the whole weight is known, and also the weight of a single atom; we shall then evidently have the required number of atoms by dividing the weight of the one atom into the weight of the whole. Now if we know the number of atoms in a body of given size, we can find the size of each atom by dividing the bulk of the whole by the number of atoms; but since we can only ascertain relative atomic weights and volumes, we suppose the volume of the mass to be unity, and the weight of the same to be the specific gravity, or weight relatively to that of water. If we then divide the atomic weight into the specific gravity, we shall have the relative number of atoms; and if we divide this number into 1, or what is the same thing, invert the fraction and divide the atomic weight by the specific gravity, we shall have the relative atomic volume. We find in this way that there are groups of simple bodies having nearly the same atomic volume, and that, when crystallized in the same form, one may be substituted for the other, giving rise to compounds of similar forms, and in some cases of similar properties, though of different chemical constitution; and on the other hand, by the differences in the grouping of the same atoms bodies may be formed having entirely different properties.

It frequently happens that in the union of different bodies in the gaseous state a condensation takes place, and the volume of the compound molecule is not equal to the sum of the volumes of atoms of which it is composed; and in other cases the reverse effect has place, and an expansion is the result.

The following table, from Faraday's lectures,* exhibits the

* [The subject matter of a course of Six Lectures on the non-metallic Elements. Lect. iv.—Nitrogen; p. 206. 16mo. London. 1853.]

combination of volumes to illustrate this subject. In this the volume of nitrogen, N, is considered as unity, and that of oxygen as half unity:

Table showing the grouping of elements in various nitrogen compounds, and the difference in quality, effected by combination.

N	
N O	Gas, inodorous, sweet, inactive. . . [Nitrous oxide.]
N O O	Gas, colorless, insoluble, oxidizing. . [Nitric oxide.]
N O O O	Liquid, acid, unstable. . . . . . [Hyponitrous acid.]
N O O O O	Gas or liquid, colored, acid, soluble. [Nitrous acid.]
N O O O O O	Liquid, acid, colorless, corrosive. . . . [Nitric acid.]
N H H H	Gas, alkaline. . . . . [Ammonia.]
N Cl Cl Cl	Liquid, detonating. . . . . [Chloride of Nitrogen.]
N I I I	Solid, detonating. . . . . [Iodide of Nitrogen.]
N C C	Gas, combustible, odorous, poisonous. . [Cyanogen.]

One of the peculiarities of the chemical combination of bodies is the neutralization, in a greater or less degree, of their attractions. Thus sulphuric acid and quick-lime, which have a powerful attraction for other substances, and are therefore highly corrosive, when united form "plaster of Paris," a neutral, inert substance. An analogous result takes place when the north and south poles of two magnets of equal power are brought into contact; if they are not of equal power, a residual action will be left in one. In a similar manner two electrified glass balls, the one plus and the other minus, both when separate attract the surrounding objects; but when brought into proximity, they rush into contact, and neutralize one another's attraction. This fact distinguishes chemical attraction from the attraction of gravitation, in which there is no neutralization of this kind, and refers the former to that condition of the ætherial medium called electric, in which it probably exists in strata of different densities around each separate molecule. The facts in

reference to this point have been classed under the head of electro-chemistry; and in this case, as in every other subdivision of our general subject, we have merely indicated a group of phenomena, each of which has occupied the attention of a number of scientists, and in some cases during a long term of years.

Until recently it was supposed that the physical qualities of bodies must depend on the nature of their elements, or in other words upon their chemical composition; but a great many substances have been discovered composed of the same elements in the same relative proportion and yet exhibiting physical and chemical properties entirely distinct one from the other. For example, according to Liebig, the oil of turpentine, the essence of lemon, oil of balsam of copaiba, oil of rosemary, oil of juniper, and many others differing widely from each other in their odor, in their medicinal effects, in their boiling points, in their specific gravities, all contain the same elements, carbon and hydrogen, and in precisely the same proportion. The crystallized part of the oil of roses, a volatile solid, of which the delicious fragrance is so highly esteemed, is a compound body containing exactly the same elements and in the same proportions as the gas employed in lighting our streets.

Such bodies are called *isomeric* (literally, of *equal parts*), and the phenomena are classed under the head of isomerism. These remarkable facts can only be accounted for by the different groupings of the atoms. They exhibit as it were the economy of Nature in producing the most multiform effects from combinations of the simplest principles, and almost revive in us the dreams of the alchemists relative to the transmutation of matter.

Combinations of this kind are generally of a very unstable character and the atoms can sometimes be made to change their positions by an impulse from without, or by the addition of heat, and to combine again, forming other substances having entirely different properties.

The changes we have mentioned are those of bodies which are formed of groups of many chemical atoms; but a fact of

a similar character has been observed with reference to bodies belonging to the class which the chemist calls simple or elementary, because they have not as yet been decomposed. Of these bodies we may mention oxygen, chlorine, sulphur, and phosphorus. They all assume under certain conditions entirely different properties to such an extent as almost to lose their identity. Oxygen, when exposed to a series of sparks of electricity, is converted into a substance called ozone, of which we shall speak more fully hereafter. Sulphur, exposed to a temperature of 226° F., is melted, and if maintained in fusion at a temperature not exceeding 300°, and then suddenly thrown into water, will be found to have suffered no change; if however the fusion be continued above 300°, the material becomes black and almost solid, and if it now be poured into water it maintains its dark color, and assumes a consistence of heated glue or softened India rubber. In this condition its medical and other properties are changed. Sulphur is also capable of assuming two different crystalline forms belonging to two primitive classes entirely distinct. Phosphorus undergoes a similar change, and chlorine, after exposure to the light, exhibits new properties. Phenomena of this kind are classed under the head of *allotropism* (literally, of *another turn* or *fashion*).

Organic Molecules.

The groups of atoms which we have thus far been considering are principally those which have been formed under the influence of what is called the chemical force, and result from the ordinary attraction of the atoms. These are comparatively simple groups; but there is another class of groups of atoms of a much more complex character, which are formed of new combinations of the ordinary atoms under the influence, or (we may say) direction of that mysterious principle called the *vital force*. We are able to construct a crystal of alum from its elements by combining sulphur, oxygen, hydrogen, potassium, and aluminum; but the chemist has not yet been found who can make an atom of sugar from the elements of which it is composed. He can

readily decompose it into its constituents, but it is impossible so to arrange the atoms artificially, as in the ordinary cases of chemical manipulation, to produce a substance in any respect similar to sugar. When the attempt is made, the atoms arrange themselves spontaneously into a greater number of simpler and smaller groups or molecules than is found in sugar, which is composed of molecules of high order, each containing no less than 45 atoms of carbon oxygen and hydrogen.

The organic molecules, (or atoms, as they are called) are built up under the influence of the vital principle, from inferior groups of simple elements. These organic molecules are first produced in the leaves of the plant under the influence of light, and subsequently go through various changes in connection with the vital process. After they are once formed in this way, they may be combined and re-combined by different processes in the laboratory, and a great variety of new compounds artificially produced from them.

But what is this vital principle which thus transcends the sagacity of the chemist and produces groups of atoms of a complexity far exceeding his present skill? It is generally known under the name of the "vital *force*"; but since the compounds which are produced under its influence are subject to the same laws as those produced by the ordinary chemical forces, though differing in complexity; and since in passing from an unstable to a more stable condition in the form of smaller groups they exhibit, as will be rendered highly probable hereafter, an energy just equivalent to the power exerted by the sunbeam under whose influence they are produced, it is more rational to suppose that they are the result of the ordinary chemical forces acting under the *direction* of what we prefer to call the vital *principle*. This is certainly not a *force*, in the ordinary acceptation of the term, or in that in which we confine this expression to the attractions and repulsions with which material atoms appear to be primarily endowed. It does not act in accordance with the restricted and uniform laws which govern the forces of inert matter, but with fore-thought, making provision far in ad-

vance of a present condition for the future development of organs of sight, of hearing, of reproduction, and of all the varied parts which constitute the ingenious machinery of a living being. Matter without the vital influence may be compared in its condition to steam, which undirected is suffered to expend its power in producing mechanical effects on the air and other adjacent bodies, marked with no special indications of design; while matter under its influence may be likened to steam under the directing superintendence of an engineer, which is made to construct complex machinery and to perform other work indicative of a directing intelligence. *Vitality*, thus viewed, gives startling evidence of the immediate presence of a direct, divine, and spiritual essence, operating with the ordinary forces of nature, but being in itself entirely distinct from them.

This view of the subject is absolutely necessary in carrying out the mechanical theory of the equivalency of heat and the correlation of the ordinary physical forces. Among the latter, vitality has no place, and it knows no subjection to the laws by which they are governed.

All the constituents of organic bodies are formed of organic molecules, and as we have said, are of great complexity and are readily disturbed and resolved into a greater number of lesser groups. Thus the constitution of cane sugar is represented by C_{12}, H_{22}, O_{11}, making in all 45 atoms. Organic bodies are therefore in what may be called a state of power, or of tottering equilibrium, like a stone poised on a pillar, which the slightest jar will overturn, they are ready to rush into closer union with the least disturbing force. In this simple fact is the explanation of the whole phenomena of fermentation, and of the effect produced by yeast and other bodies, which being themselves in a state of change, overturn the unstable equilibrium of the organic molecules and resolve them into other and more stable compounds. Fermentation then simply consists in the running down of organic molecules from one stage to another, changing their constitution, and at last arriving at a neutral state. There is however one fact in connection with the running down of

the organic molecules which deserves particular attention, namely, that it must always be accompanied with the exhibition of power or energy, with a disturbance of the ætherial equilibrium in the form of heat, sometimes even of light, or perhaps of the chemical force, or of that of the nervous energy, in whatever form of motion the latter may consist. It is a general truth of the highest importance in the study of the phenomena of nature that whenever two atoms enter into more intimate union, heat or some form of motive power, is always generated. It may however be again immediately expended in effecting a change in the surrounding matter, or it may be exhibited in the form of one of the radiant emanations.

Balance of Nature.—The term balance of organic nature was first applied, we think, by Dumas to express the relations between matter forming animals and vegetables, and the same matter in an inert condition. We shall apply the term "balance of nature" in a more extended sense, and include within it the balance of power, as well as the transformations of matter. The amount of matter in the visible universe is supposed to remain the same, though it is subject to various transformations, and appears under various forms, —now built up into organic molecules, and now again resolved into the simple inorganic compounds. The carbon and other materials absorbed from the air by the plant is given back to the atmosphere by the decaying organisms, and thus what may be called a constant balance is preserved. But this balance (if we may so call it) does not alone pertain to the matter, but also to the energy which is employed in producing these changes. It may disappear for a while, or may be locked up in the plant or the animal, but is again destined to appear in another form and to exert its effects perhaps in distant parts of celestial space.

To give precision to our thoughts on this subject let us suppose that all the vegetable and animal matter which now forms a thin pellicle at the surface of the earth were removed —that nothing remained but the germs of future organisms buried in the soil and ready to be developed when the proper

influences were brought to bear upon them. Let us further suppose the sun to cease giving emanations of any kind into space. The radiation from the earth, uncompensated by impulses from the sun, would soon reduce the temperature of every part of the surface to at least 60° below zero; all the matter and liquid substances capable of being frozen would be reduced to a solid state; the air would cease to move, and universal stillness and silence would prevail.

Let us now suppose that the sun were to give forth rays of heat alone; these would radiate in every direction from the celestial orb, and an exceedingly small portion of them, in comparison with the whole, would impinge against the surface of our distant planet, would melt the ice first on the equator, then on the more northern and southern parts of the globe, and finally their genial influence would be felt at the poles. The air would be unequally rarefied in the different zones, the winds would again be called forth, vapor would rise from the ocean, clouds would be formed, rain would descend, and storms and tempests would resume their sway.

If the sun should again intermit its radiation all these motions would gradually diminish and after a time entirely cease; the heat given to the earth would in part be retained for awhile, but in time would be expended; the water would slowly give out its latent heat and be again converted into ice. Something of this kind takes place in the northern and southern parts of the earth during the different periods of summer and winter. Since the mean temperature of the earth does not vary from year to year, it follows that all the excess of heat of summer received from the sun is given off in winter, and hence the impulses from this luminary which constitute all the energy producing the changes on the surface of the earth, merely lingering awhile, are again sent forth into celestial space, changed it may be in form, but not in the amount of their power. The solar vibrations have lost none of their energy, for the water has returned to the state of ice, and the surface of the earth is again in the same condition in which it was before it received the solar impulse.

The energy of the solar vibrations communicated to the ice modifies its cohesion, converting it into the liquid state, and the ice again becoming solid gives out the same amount of heat in a less energetic form. Even the motive power of the wind is expended by the friction of its particles in producing a portion of the heat which gave rise to its motion, and this also is radiated into celestial space.

But the most interesting part of our inquiry relates to the effects which the radiation alone of heat from the sun would have on the vegetable germs buried in the soil. If these germs were enclosed in sacs filled with starch and other organic ingredients, stored away for the future use of the young plant, as in the case of the tuber of the potato, or the fleshy part of the bean, as soon as the sun penetrated beneath the surface in sufficient degree to give mobility to the complex organic molecules of which these materials consist, (the proper degree of moisture also supposed to be present,) germination would commence. The young plant would begin to be developed, would strike a rootlet downward into the earth, and elevate a stem towards the surface furnished with incipient leaves. The growth would continue until all the organic matter in the tuber or sac was exhausted; the further development of the plant would then cease, and in a short time decay would commence.

But let us dwell a few minutes longer on the condition of the plant and the tuber before the downward action becomes the subject of consideration. If we examine the condition of the potato which was buried in the earth, we shall find remaining of it nothing but the skin, which will probably contain a portion of water. What has become of the starch and other matter which originally filled this large sac? If we examine the soil which surrounded the potato, we do not find that the starch has been absorbed by it; and the answer which will therefore naturally be suggested is, that it has been transformed unto the material of the new plant, and it was for this purpose originally stored away. But this, though in part correct, is not the whole truth; for if we weigh a potato prior to germination, and weigh the young

plant afterward we shall find that the amount of organic matter contained in the latter is but a fraction of that which was originally contained in the former. We can account in this way for the disappearance of a *part* of the contents of the sac, which has evidently formed the pabulum of the young plant. But here we may stop to ask another question: By what power was the young plant built up of the molecules of starch? The answer would probably be, by the exertion of the vital force; but we have endeavored to show that vitality is a *directing principle,* and not a mechanical power, the expenditure of which does work. The conclusion to which we would arrive will probably now be anticipated. The portion of the organic molecules of the starch, &c., of the tuber, as yet unaccounted for, has run down into inorganic matter, or has entered again into combination with the oxygen of the air, and in this running down, and union with the oxygen, has evolved the power necessary to the organization of the new plant.

If we examine the skin of a potato, we shall find it perforated by innumerable holes, through which the oxygen penetrates into the interior to enter into combination with the starch, (or in other words, to burn it by a slow combustion,) and through which the carbonic acid and vapor of water again find their way into the atmosphere. We see from this view that the starch and nitrogenous materials, in which the germs of plants are imbedded, have two functions to fulfil; the one to supply the pabulum of the new plant, and the other to furnish the power by which the transformation is effected, the latter being as essential as the former. In the erection of a house, the application of mechanical power is required as much as a supply of ponderable materials.

But to return to our first supposition. We have said (and the assertion is in accordance with accurate observation) that the plant would cease to increase in weight under the mere influence of heat, however long continued, after the tuber was exhausted. Some slight changes might indeed take place; a small portion of pabulum might be absorbed from the earth; or one part of the plant might commence to decay,

and thus furnish nourishment to the remaining parts; but changes of this kind would be minute, and the plant, under the influence of heat alone, would in a short time cease to exist.

Let us next suppose the sun to commence emitting rays of *light*, in addition to those of heat. These, impinging against the earth, would probably produce some effects of a physical character; but what these effects would be we are unable, at the present time, fully to say. We infer however that the light, not immediately reflected into space, would be annihilated; but this could not take place without communicating motion to other matter. It would probably be transformed into waves of heat of feeble intensity.

Let us now suppose, in addition to heat and light, the chemical rays to be sent forth from the sun. These would also produce various physical changes, the most remarkable of which would be in regard to the plant.

The carbonic acid of the atmosphere, in contact with the expanding surface of the young leaves, would be absorbed by the water in their pores, and in this condition would be decomposed by the vibrating impulses which constitute the chemical emanation. The atoms of carbon and oxygen, of which the carbonic acid is composed, would be forcibly separated; the atoms of oxygen would be liberated in the form of gas, and the carbon be absorbed to build up, under the directing influence of vitality, the woody structure of the plant. In this condition the pabulum of the plant is principally furnished by the carbonic acid of the air, while the impulses of the chemical ray furnish the primary power by which the de-composition and the other changes are effected. This is the general form of the process, leaving out of view minute changes, actions, and re-actions, which must take place in the course of organization.

All the material of which a tree is built up, (with the exception of that comparatively small portion which remains after it has been burnt, and constitutes the ash,) is derived from the atmosphere. That this is so can be proved by growing a plant in perfectly pure flint sand, to which a

minute quantity of foreign substance is added, and sprinkling with distilled water. In this case the plant will yield the usual amount of carbon or charcoal, although there was none in the soil in which it grew.

In the decomposition of the carbonic acid by the chemical ray a definite amount of power is expended, and this remains (as it were) locked up in the plant so long as it continues to grow; but when it has reached its term of months or years, and some condition has been introduced which interferes with the balance of forces, then a reverse process commences, the plant begins to decay, the complex organic molecules begin to run down into simpler groups, and then again into carbonic acid and water. The materials of the plant fall back into the same combinations from which they were originally drawn, and the solid carbon is returned in the form of a gas to the atmosphere whence it was taken. Now the power which is given out in the whole descent is, according to the dynamic theory, just equivalent to the power expended by the impulse from the sun in elevating the atoms to the unstable condition of the organic molecules. If this power is given out in the form of vibrations of the ætherial medium constituting heat it will not be appreciable in the ordinary decay—say of a tree, extending as it may through several years; but if the process be rapid, as in the case of combustion of wood, then the same amount of power will be given out in the energetic form of heat of high intensity. This heat will again radiate from the earth, and in this case, as in that we have previously considered, the impulse from the sun merely lingers for a while upon the earth, and is then given back to celestial space changed in form, but undiminished in quantity. It may continue its radiating course through stellar space until it meets planets of other systems; but to attempt to trace it further would be to transcend the limits of inductive reason, and to enter those of unbridled fancy.

In the process we have described, the carbon, hydrogen, and other substances which are absorbed from the atmosphere are returned to this great reservoir to be used again,

and it may be to undergo the same changes many times in succession. The earthy materials are again returned to the earth, and all the conditions, as far as the individual plant which we are considering is concerned, are the same as they were at the beginning. The absorption of power in the decomposition of the carbonic acid gas, and its evolution again when the re-composition is produced of the same atoms, is precisely analogous to that which takes place in forcibly separating the poles of two magnets, retaining them apart for a certain time, and suffering them to return by their attractive force to their former union. The energy developed in the approach of the magnets towards each other is just equal to the force expended in their separation.

By extending this reasoning to the vast beds of coal which are stored away in the earth, we are brought irresistibly to the conclusion that the power which is evolved in the combustion of this material, now so valuable an agent in the processes of manufacture and locomotion, is merely the equivalent of the force which was expended in de-composing the carbonic acid which furnished the carbon of the primeval forests of the globe; and that the power thus stored away millions of years before the existence of man, like other preordinations of Divine Intelligence, is now employed in adding to the comforts and advancing the physical and intellectual well-being of our race.

In the germination of the plant a part of the organized molecules runs down into carbonic acid to furnish power for the new arrangement of the other portion. In this process no extraneous force is required: the seed contains within itself the power and the material for the growth of the new plant up to a certain stage of its development. Germination can therefore be carried on in the dark, and indeed the chemical ray which accompanies light retards rather than accelerates the process. Its office is to separate the atoms of carbon from those of oxygen in the decomposition of the carbonic acid, while that of the power within the plant results from the combination of these same elements. The forces are therefore antagonistic, and hence germination is more

rapid when light is excluded; an inference borne out by actual experiment.

Animal Organism.

Besides plants, there is another great class of organized beings, viz: animals; and as we commenced with the consideration of the seed in the first case, let us begin in this with the egg. This (as is well known) consists of a sac or shell containing a mass of organized molecules formed of the same elements of which the plant is composed, viz: carbon, hydrogen, oxygen, and nitrogen, with a minute portion of sulphur and other substances. Indeed this material is derived exclusively from the animal kingdom. Without attempting to describe the various transformations which take place among these organized molecules, a task which far transcends our knowledge or even that of the science of the day, we shall merely consider the general changes which occur of a physical character.

As in the case of the seed of the plant, we presume that the germ of the future animal pre-exists in the egg, and that by subjecting the mass to a degree of temperature sufficient perhaps to give greater mobility to the molecules, a process similar in its general effect to that of the germination of the seed commences. Oxygen is absorbed through some of the minute holes in the shell, and carbonic acid constantly exhaled from others. A portion then of the organic molecules begins to run down, and is converted into carbonic acid and, possibly, water. During this process power is evolved within the shell,—we cannot say, in the present state of science, under what particular form; but we are irresistibly constrained to believe that it is expended under the direction again, of the vital principle, in re-arranging the organic molecules, in building up the complex machinery of the future animal, or developing a still higher organization, connected with which are the mysterious manifestations of thought and volition.

In this case, as in that of the potato, the young animal as it escapes from the shell weighs less than the material of the

egg previous to the process of incubation. The lost material in this case as in the other has run down into an inorganic condition by combining with oxygen, and in its descent has developed the power to effect the transformation we have just described.

We have seen in the case of the young plant that after it escapes from the seed and expands its leaves to the air, it receives the means of its future growth principally from the carbon derived from the de-composition of the carbonic acid of the atmosphere, and its power to effect all its changes from the direct vibratory impulses of the sun. The young animal however is in an entirely different condition; exposure to the light of the sun is not necessary to its growth or existence; the chemical ray by impinging on the surface of its body does not de-compose the carbonic acid which may surround it, the conditions necessary for this de-composition not being present. It has no means by itself to elaborate organic molecules, and is indebted for these entirely to its food. It is necessary therefore that it should be supplied with food consisting of organized materials, that is of complex molecules in a state of instable equilibrium, or of power. These molecules have two offices to perform, one portion of them, by their transformations, is expended in building up the body of the animal, and the other in furnishing the power required to produce these transformations, and also in furnishing the energy constantly expended in the breathing, the pulsations, and the various other mechanical motions of the living animal. We may infer from this that the animal in proportion to its weight before it has acquired its growth will require more food than the adult unless all its voluntary motions be prevented; and secondly, that more food will be required for sustaining and renewing the body when the animal is suffered to expend its muscular energy in labor or other active exercise.

The power of the living animal is immediately derived from the running down of the complex organized molecules of which the body is formed, into their ultimate combination with oxygen in the form of carbon, water, and ammonia.

Hence oxygen is constantly drawn into the lungs, and carbon is constantly evolved. In the adult animal when a dynamic equilibrium has been attained the nourishment which is absorbed into the system is entirely expended in producing the power to carry on the various functions of life, and to supply the energy necessary to perform all the acts pertaining to a living, sentient, and it may be, thinking being. In this case, as in that of the plant, the power may be traced back to the original impulse from the sun, which is retained through a second stage, and finally given back again to celestial space, whence it emanated. All animals are constantly radiating heat, though in different degrees, the amount in all cases being in proportion to the oxygen inhaled and the carbon exhaled. The animal is a curiously contrived arrangement for burning carbon and hydrogen, and the evolution and application of power. In this respect it is precisely analogous to the locomotive, the carbon burnt in the food and in the wood performing the same office in each. The fact has long been established that power cannot be generated by any combination of machinery. A machine is an instrument for the application of power, and not for its creation. The animal body is a structure of this character. It is admirably contrived, when we consider all the offices it has to perform, for the purpose to which it is applied, but it can do nothing without power, and that, as in the case of the locomotive, must be supplied from without. Nay more, a comparison has been made between the work which can be done by burning a given amount of carbon in the machine, man, and an equal amount in the machine, locomotive. The result derived from an analysis of the food in one case and the weight of the fuel in the other, and these compared with the quantity of water raised by each to a known elevation, gives the relative working value of the two machines. From this comparison, made from experiments on soldiers in Germany and France, it is found that the human machine, in consuming the same amount of carbon, does four and a half times the amount of work of the best Cornish engine. The body has been called "the

house we live in," but it may be more truly denominated the machine we employ, which furnished with power and all the appliances for its use, enables us to execute the intentions of our intelligence, to gratify our moral natures, and to commune with our fellow beings.

This view of the nature of the body is the furthest removed possible from materialism; it requires a separate thinking principle. To illustrate this, let us suppose a locomotive engine equipped with steam, water, fuel,—in short, with the potential energy necessary to the exhibition of immense mechanical power; the whole remains in a state of dynamic equilibrium, without motion or sign of life or intelligence. Let the engineer now open a valve which is so poised as to move with the slightest touch, and almost by mere volition, to let on the power to the piston; the machine now awakes, as it were, into life. It rushes forward with tremendous power, it stops instantly, it returns again, it may be at the command of the master of the train; in short, it exhibits signs of life and intelligence. Its power is now controlled by mind—it has, as it were, a soul within it. The engine may be considered as an appendage or a further development of the body of the engineer, in which the boiler and the furnace are an additional capacious stomach for the evolution of the power; and the wheels, the cranks and levers, the bones, the sinews, and the muscles by which this power is applied.

There is however one striking difference between the animal body and the locomotive machine which deserves our special attention, namely, the power in the body is constantly evolved by burning (as it were) parts of the materials of the machine itself, as if the frame and other portions of the wood-work of the locomotive were burnt to produce the power, and then immediately renewed. The voluntary motion of our organs of speech, of our hands, of our feet, and of every muscle in the body is produced, not at the expense of the soul, but at that of the material of the body itself. Every motion manifesting life in the individual is the result of power derived from the death (so to speak) of a part of his

body. We are thus constantly renewed and constantly consumed, and in this consumption and renewal consists animal life. When the proper balance between these two processes is destroyed the derangement and death of the body ensue. The rational, directing, thinking, willing soul, analogous to that Divine intelligence manifested in all the works of Nature, dissolves its connection with matter, and finds in another, and perhaps successive conditions, an immortal existence.

In this great perpetual circle of change nothing is lost. The earthy matter absorbed by the roots of the plant is given back to the earth in the ejectments and decay of the animal body; the carbon, the hydrogen, the nitrogen, are returned to the air whence they were drawn; the solar impulses by which all the transformations were effected, are restored unaltered in quantity to the celestial space; and in the case of man, the soul, fraught with the moral effects of its connection with matter, returns to its Divine Creator, the source of all power, moral, intellectual, and physical.

Mechanical Energy.

The last remarks will lead us naturally to the subject of mechanical energy and the correlation of physical forces, a comparatively new class of ideas, which is at present occupying the attention of some of the first men of Europe and this country. Indeed, one reason which has induced us to adopt the atomic theory in this essay is, that we might give the clearest and simplest view of these new and interesting ideas, as well as some of the deductions which have been made from them. The fact has been long conclusively established in the minds of scientific men, that matter cannot be annihilated, except by the almighty fiat of Him who called it into existence; and the idea has been lately adopted, that the natural forces associated with matter, namely, the attractions and repulsions, are also as indestructible as the matter itself; moreover, the tendency of scientific speculation at the present day is to the conclusion that all energy, as it is called, or that which produces the changes in the material

universe, is due to the movements produced by attraction and repulsion of the atoms in passing from a primordial state of instability to one of final stability or relative rest. It must be evident to any person who is acquainted with the simplest principles of mechanics, that in a universe in which all the atoms are in equilibrium, or have approached each other as nearly as possible, there can be no spontaneous motion. Such a universe must ever remain, in all its parts, a dead, inert, and lifeless mass. It can only be awakened to life and motion by the application of power from without. Mechanical energy is only exhibited while two atoms are rushing together; when they have united in combination, they exhibit an apparent neutralization of all power to produce change in themselves or other bodies.

"Fill," says Professor Faraday, "an India-rubber bag with a mixture of oxygen and hydrogen in the proportion of 8 parts to 1 by weight; and blowing with it a number of soap-bubbles in a large dish, apply a lighted taper to the bubbles and observe the result. It is a violent deafening explosion, attended with the evolution of light and heat, giving evidence of tremendous power. But now we come to the result of this explosion, which is water — *nothing but water*. To me the whole range of natural phenomena does not present a more wonderful result than this. Well known, and familiar though it be, a fact standing on the very threshold of chemistry, it is one over which I ponder again and again with wonder and admiration. To think that these two violent elements, holding in their admixed parts such energy, should wait until some disturbance is effected, and then rush furiously into combination, and form the bland and un-irritating liquid water, is to me, I confess, a phenomenon which awakens new feelings of wonder as often as I view it."*

Wonderful as this may appear, it is but a simple illustration of a general law. The power exhibited was in the momentum produced by the energetic action of the two atoms on each other, and the consequent high velocity with which they rushed into union. The noise produced was due to the intense agitation given to the air; the light and heat to the

*[Faraday's Six Lectures on the non-metallic Elements. Lect. iii, pp. 175, 176.]

agitation of the ætherial medium; and these together are equal to the energy generated by the reciprocal motion of the atoms. If by any means a force were applied to separate the atoms to the same distance at which they were at first, this force would be just equal to that due to the rushing together of the atoms. Two atoms separated, and in a condition to be violently drawn together, are said to be in a state of *energy* or *power;* but when they have entered into combination, they are then in a state of inertness. The same may be said of a weight elevated above the surface of the earth. A certain amount of muscular power must be exerted to overcome the attraction of gravitation, and to raise the weight to the given height, say ten feet. It is then in a state of power, or in a condition to produce permanent changes in matter, and other effects which we technically denominate "work."

The energy developed in the weight may be employed to drive a pile into the ground, or it may be made to turn a mill and grind corn; but the work done in these two cases, when properly measured, will be the same, and just equal to that expended in elevating the weight. If the weight be raised to double the height, twice the force will be expended in accomplishing this effect, and the weight in its descent to the earth will also do a corresponding amount of work. The explanation of the development of the energy exhibited in the fall of a body from a height will be plain when we consider that gravity acts on the mass with a force proportioned to the number of pounds in weight at every point in its descent; and if we suppose that in the first this attraction gave it a certain velocity, and gravity were then to cease, the body, on account of its inertia, would continue to descend with this velocity to the end of its course. But if the attraction continues to act, new impulses are imparted at every instant, and the velocity will continually increase until it reaches the ground, where it will produce an effect which is the equivalent of the power accumulated in its descent. The mechanical energy of matter therefore is measured by the distance of the atoms into the intensity of the attraction at the differ-

ent points of their path of approach. If the atoms of any part of the material universe are in the condition of the atoms of oxygen and hydrogen after they have united to form water—that is, in the closest approximation and a complete neutralization of their affinities—the matter in this portion of space will be entirely inert, and unless disturbed by extraneous force, no change can take place among its parts. Matter wanting that peculiar characteristic which eminently distinguishes mind, namely, spontaneity of action, all will be in perfect quiescence.

From the researches of the geologist, the chemist, and the physicist, we are enabled to assert that such is the condition of our earth and its attendant satellite. All the chemical elements which are found in the crust of the globe have gone into a state of permanent quiescence. The metals and oxygen have united to form oxides, and these with the acids to form other stable compounds; and were it not for the disturbing influence of the impulses from the sun, the present system of continued change, of growth and decay, of storms and of calms, would cease, and the whole surface of our planet would exhibit a dreary desolation of darkness and stillness, of silence and death. Indeed as it is, the changes and ever-varying phenomena in which we are so much interested, and a knowledge of which constitutes the highest earthly wisdom, are confined to an almost infinitesimal pellicle at the surface of the earth. Organic matter is found but a few feet below the surface of the soil, and plants cannot exist in the ocean beyond the depth to which the rays of the sun penetrate. But this state of things has not always existed. It is conclusively proved by the past history of the globe, as written upon the rocks which form its outer strata, that its atoms were once in a state of intense agitation, or in other words, that the globe was in a condition of high temperature, and that the vibrations have been imparted to the surrounding ætherial medium and and thus radiated off into space. We arrive at this conclusion, not only from an examination of the condition of the strata, but from the fact that wherever we penetrate beneath

the surface, beyond the depth of the influence of external climate, the temperature uniformly increases at the rate of about 1° F. for every 50 feet. Our globe then consists of a mass of matter which has been gradually cooled from a state of intense heat, and at its surface has arrived at a condition of equilibrium, the heat which its surface gives off into space being just compensated by that received from the sun. The permanency of our temperature therefore depends upon that of the great central luminary of our system itself. But whether

> "The sun himself shall fade, and ancient night
> Again involve a desolate abyss,"

must be left for future consideration.

The ideas which are here given had their origin in the attempts which were made to produce self-moving machines. The possibility of such contrivances appeared to be sanctioned by the apparently spontaneous motion of men and lower animals. The idea that these motions were the results of the chemical action of food had not yet entered the mind; and it was only after many fruitless attempts, and the expenditure of much thought, time, and labor that the conclusion was at length arrived at that a machine is a mere instrument for the application and modification of power or energy, and that in no case can it do more work or produce more changes in matter, or in other words, it can break apart no more atoms than are equivalent to the power which has been applied to it. The same amount of power which we apply at one extremity of a machine, properly estimated, is equal to the sum of the resistances at the other, and the two precisely balance each other. From considerations of this kind we arrived at the conception of the correlation of the physical forces and the re-conversion of the equivalent of one into that of the other.

We may do the same work by heat properly applied, or by a fall of water, or by muscular energy. For example, a disc of iron may be made to revolve rapidly with a mill driven by a fall of water, and if this is allowed to rub with some pressure against another iron plate a great amount of

friction will be produced; the mechanical collision of the surfaces will set the atoms of the plates in that state of vibration which constitutes heat, and which, if unobstructed, will be communicated to the surrounding ætherial medium and radiated to adjacent bodies or off into celestial space. But if detained and applied it may be used to produce changes in matter, such as the boiling of water, the driving of a steam engine, and other objects. Now, if it were possible to collect and concentrate all the impulses of the heat vibrations, and apply them without loss by means of a machine to the elevation of water, the quantity thus raised and the height to which it is raised would be precisely equal to the height and quantity of water, the fall of which produced the first effect. Similarly, if by a steam engine we put in motion the plate of a large electrical machine and disturb the equilibrum of the æther, condensing a portion of it in one part of space and rarefying it in another portion, the force which would be exerted in the restoration of the equilibrium, or in the electrical discharge, would be just equal to the amount of energy exerted in producing the coerced condition. If in this case the coerced equilibrium is retained for a day, a year, or a century, so long the amount of energy expended to produce it will, as it were, be locked up but not lost. It will be ready to appear and do work as soon as the detent which prevents the commencement of motion is removed. As a further example of this, suppose a heavy weight to be elevated by steam power to the top of a high pillar, and there placed on an equipoise, so that the least force applied may overturn it and enable it to commence its fall. In its descent it will receive at every instant a new impulse from gravity, and when it arrives at the ground it will expend its accumulated energy in penetrating the surface and in the production of heat, sound, and tremors of the earth. When the weight is resting on the top of the pillar, ready to fall off with the slightest touch, it is said to be in a state of potential energy; and when it has almost reached the earth and is moving with the full velocity of the fall, it has converted its potential energy into actual power.

The general conclusion which has been arrived at is that the different physical energies—whether called chemical action, heat, light, electricity, magnetism, muscular motion, or mechanical power, are all referable to the disturbance of the equilibrium of the atoms and the subsequent restoration due to their attractions and repulsions; and that all these forms of energy are in one sense convertible into each other, or in other words the force generated in the restoration of the equilibrium in one case is sufficient to disturb it, though in a different form perhaps, in another. We must guard against the erroneous idea which some have inconsiderately adopted, that one form of power can be actually converted into another, as heat into electricity, or the converse. The theory of energy merely declares that the power exhibited in the electrical discharge is the equivalent of the muscular energy expended in charging the battery, and not that muscular energy is converted into electricity.

The origin of heat produced by friction for a long time perplexed the most sagacious philosophers. Our celebrated and ingenious countryman, Count Rumford, caused a quantity of water to boil for several hours by the heat generated in boring a cannon; and after the process was ended, he found that the borings and the cannon contained as much heat as at the commencement of the experiment. From this result he boldly proclaimed that heat was not matter, but the vibrations of the atoms of matter, and that in his experiment the heat was generated by the friction of the drill on the metal.

Later researches have constantly tended to strengthen the probability of this view, and even to establish the general fact, that when mechanical power is produced by the expenditure of heat, a quantity of heat disappears, bearing a fixed proportion to the power produced; and conversely, that when heat is produced by the expenditure of mechanical power, the quantity of heat produced bears a fixed proportion to the power expended. Thus in the case of a steam engine doing no work, the quantity of heat given

out in the waste-pipe would be just equal to that received into the boiler, provided there were no loss from conduction and radiation; but in the engine drawing up water, for example, a quantity of heat is actually annihilated in doing the work. The vibrations of the atoms which constitute heat are stopped in giving motion to the piston-rod. Conversely, if the water which has been pumped up to an elevation were made in its descent to produce heat by means of revolving disks, the amount generated would be just equal to that which disappeared in the other case.

For practical purposes it is therefore of great importance that the ratio of equivalents of heat and mechanical power should be accurately determined, and for this purpose James P. Joule, of Manchester, has made a series of most delicate and beautiful experiments on the heat evolved by the revolution of paddle-wheels in baths of water, mercury, or oil. Motion was given to the paddle-wheels by a known weight descending from a given height; the amount of heat was found to be precisely the same with a given expenditure of mechanical power, whether the wheel revolved in water, mercury, or oil, proper allowance being made for the different densities and the different capacities of these bodies for heat. In this way, he found that the fall of a weight of one pound through 772 feet, or what would be the equivalent, the fall of a weight of 772 pounds through one foot, is just sufficient to raise the temperature of one pound of water one degree of Fahrenheit's scale. Seven hundred and seventy-two pounds falling through one foot is therefore considered as the unit of the working power of heat; and in honor of the investigator who has thus enriched modern science with one of its most valuable means of calculation, applicable to every part of physical research, it is denominated "Joule's unit." By it we are enabled to express in terms of the descent of a weight the equivalency of all the forces of Nature, and thus to reduce the mechanical conception of their relations to its greatest simplicity, and to apply mathematical reasoning to a variety of problems heretofore excluded from the province of this great logical instrument, so essential in

the deduction of effects from complex relations. The descent of a weight is chosen, because it is perhaps the most familiar, and of the easiest conception and application. The value of a fall of water is always estimated by the quantity of liquid multiplied by the height through which it descends. If we multiply these together, and divide by 772, we shall have the number of degrees of heat that this will impart to a pound of water; and conversely, by knowing the number of degrees of heat as measured by the number of pounds of water raised one degree, we shall have the number of pounds of water which can be elevated to a given height by a perfect machine; and when such effects are submitted to this calculation, we find that the steam engine, in its most improved form, is far from utilizing all the heat applied to it; by far the greater portion is expended in the separation of the atoms of water in radiation, in overcoming friction, and in the production of vibration and useless motion.

Mr. Joule also established the relations of equivalence among the energies of chemical affinities of heat, of combination, or of combustion, of electrical currents in the galvanic battery, and in electro-magnetic machines, and of all the varied and interchangeable manifestations of caloric action and mechanical force which accompanies them. A series of experiments has also been made on the heat of animals, which is found to be the equivalent of the chemical combination of the food and the oxygen which they inhaled.

The influence which investigations of this kind are to have on the future history of mechanical arts and the production of labor-saving machines, and on the increased power of man in controlling the innate forces of matter, it is impossible to estimate.

"The food of animals is either vegetable, or animals fed on vegetables, or ultimately vegetable after several removes. Except mushrooms and other fungi, which can grow in the dark, are nourished by organic food like animals, and like them absorb oxygen and exhale carbonic acid,—all known vegetables get the greater part of their substance (certainly all their combustible matter) from the decomposition of carbonic acid and water absorbed by them from the air and

soil. The separation of carbon and of hydrogen from oxygen in these de-compositions is an energetic effect equivalent to the heat of re-combination of those elements by combustion or otherwise. The beautiful discovery of Priestley, and the subsequent researches of Sennebier, De Saussure, Sir Humphry Davy, and others, have made it quite certain that those de-compositions of water and carbonic acid only take place naturally in the day-time, and that light falling on the green leaves, either from the sun or an artificial source, is an essential condition without which they are never effected. There cannot be a doubt but that it is the dynamical energy of the luminiferous vibrations which is here efficient in forcing the particles of carbon and hydrogen away from those of oxygen, towards which they are attracted with such powerful affinities, and that luminiferous motions are reduced to rest to an extent exactly equivalent to the potential energy thus called into being. Wood fires give us heat and light which have been got from the sun a few years ago. Our coal fires and gas lamps bring out, for our present comfort, heat and light of a primeval sun, which have lain dormant as a potential energy beneath the seas and mountains for countless ages." (Prof. William Thomson.)

A striking example of the transformation, as it were, of the force of motion into heat is exhibited by an article of apparatus now in the cabinet of the Smithsonian Institution and devised by M. Leon Foucault, of Paris. Between the poles of a strong electrio-magnet a heavy metallic disc is made to rotate, and although the revolving body does not touch the magnet, yet its motion is stopped by it in a few seconds. The momentum of the disc which is thus overcome gives rise to heat; for the re-action of the magnet produces a current of electricity, and in the resistance to this the heat is generated. A body in motion is in a state of power, and it cannot come to rest without producing some effect on the surrounding matter. The ultimate effect in this case is an agitation of the atoms of the metal.

Condition of the Earth in Space.

Having given a general view of the atomic theory in its widest generalizations, we now propose to consider its applition to the physical phenomena of our globe. For this pur-

pose we will briefly recall some of the elementary facts of astronomy.

The earth is a globe very slightly flattened at the poles, isolated in space, supported upon nothing, and only connected with other bodies of the universe by the all-pervading force of attraction. In this free space it turns upon itself with a regular motion around an ideal axis which pierces its surface at two opposite points or poles, which have never sensibly varied their position. It also moves in space describing around the sun in the course of a year a slightly elliptical curve called its orbit. But this movement of translation around the sun does not interfere with the rotation of the earth around its axis; for in accordance with the second fundamental law of motion, two motions of this kind may exist in a body at the same time. If the earth's axis were at right angles to the plane of its orbit, but slight variations would be found in the temperature at its surface in different periods of the year. The axis is not however thus placed, but is inclined at an angle of about twenty-three and a half degrees to the plane above mentioned; and this fact, which at first sight might appear of little consequence, in reality produces all the alternations of seasons, and is connected with all the changes of climate of the surface of the globe. Gradual changes of climate cannot be produced by a change in the axis of rotation, as some have supposed, since this would alter the whole form of the earth, and produce other changes incompatible with the facts of observation.

The position, the form, and the movement of the earth are similar to those of the other planetary masses which we see isolated in space under the form of globes, turning around on an axis within themselves, and around the sun in elliptical curves. While we observe that the earth is the centre of the orbit of our moon, we see that four moons turn around Jupiter, seven around Saturn, and six around Uranus. A planet, with the moons which accompany it, form what is called a *planetary system*, and all the planets taken together, with the sun, constitute what is denominated the *solar system*. In this system the earth occupies the third place from the

sun, from which it is removed ninety-five millions of miles at its mean distance. Neptune occupies the most distant limit, and is more than thirty times farther removed than the earth from the principal centre of influence. But these distances, though greatly beyond our definite conceptions, are nothing in comparison with the intervals which separate the sun from the fixed stars. These bodies like the sun are self-luminous, and are without doubt centres of planetary systems; but they are at such an inconceivable distance that light itself, which requires but eight minutes to reach us from the sun, occupies years of time in its journey from the nearest of them. But all the stars which are visible to the naked eye form only a single group, which, if viewed at a sufficient distance, would appear in the heavens as only a luminous cloud or spot, and would resemble the nebulous patches which we perceive here and there in different parts of the heavens by the aid of powerful telescopes. This universe, unbounded (at least to human intelligence)—is composed of isolated groups of stars, and perhaps of orders of arrangement still more elevated. In this magnificent assembly our nebula is only a spot in the infinity of spots; our sun is only a star in the midst of the stars of the group to which it belongs; and among the planets which revolve around our sun, the earth is one of an inferior order.

Starting from the grouping of gross atoms, which we have previously given, and extending the analogy, the thought has been expressed that our earth might be compared to an atom; the earth and moon to a compound atom; the whole system to a molecule; and our sun, and all the stars of the group to which it belongs, as the great solid of solids, and thus in one conception embracing the whole material universe. But to limit our speculations we may inquire whether the infinity of stars by which we are surrounded has any influence upon the climate and temperature of this earth.

Influence of the stars.—It is well known that at one time the stars were supposed to influence human destiny, and though astronomy has discarded most of the pretensions of

her progenitor—astrology, yet in this instance, modern science has shown that the stars have really a physical influence upon our earth and on every other planet of our system. If from any point in space a line be extended in thought in any direction, it will ultimately meet a radiating body; and hence every point in space must be constantly traversed from all directions with radiating impulses which give it a definite and fixed temperature. For example, our sun sends a ray to every point of the universe, and every other sun sends a ray to the same point, and the sum of all these rays will constitute the temperature of that point. We say the *temperature* of that point, by which we mean the effect which would be produced on a thermometer if put in that place; not that there is any temperature in celestial space, for this, as we have seen, belongs to gross matter, and is produced by the motion of its atoms. The term however is convenient, and we shall continue to use it.

If the radiating power of the suns remained without change, then the temperature of each point in space would be unchangeable. From this consideration it follows that the planetary space in which our earth is moving has in one sense a fixed temperature (independent of the heat of the sun,) derived from all the other suns of the universe; and this temperature, as we shall hereafter see, has a marked influence on the temperature of the globe.

We shall return to this subject again, and at present shall merely state that at the polar regions of our earth during the months of winter, the space immediately contiguous to the surface is screened from the heat of the sun, and consequently the earth by its radiation, must fall in temperature nearly to that of celestial space. A similar screening takes place in succession on all parts of the earth's surface during the night; and as the loss of heat by radiation depends (as we shall see) upon the temperature of the space into which the rays are sent, every part of the earth's surface must be affected more or less by the temperature of interplanetary space; and if this were to vary, though our sun might continue constant in its emanation, the average terrestrial temperature would be subject to a change.

We cannot however explain the effect of the temperature of planetary space upon our earth until we have further considered the subject of heat.

Heat of the Earth.

The temperature of the earth is derived from three sources, namely, the *original* heat of the earth, the heat of celestial space, and the heat of the sun. Before however giving an account of the heat derived from these sources, we shall consider the character of radiant heat, as developed by the researches of Melloni and others.

Radiant Heat.—The impulses which are received from the sun, as we have seen, are far from being simple in their nature. We know that a beam from this luminary consists of at least four different classes of emanations, namely, of light, of heat, of chemical action, and of phosphorogenic effect. We also know that the first class, that of light, consists of a number of different emanations which produce in us the sensations of the different colors of the spectrum, and from analogy we might have inferred that the heat emanations also consist of a number of rays, possessing different properties, and producing at the surface of the earth different physical and perhaps physiological effects.

Let us begin with heat of the lowest intensity, or that which is supposed to be composed of waves of the greatest length; for example, the radiation from a canister of hot water suspended in mid-air. If this have a temperature in the least degree above that of the surrounding bodies, they will increase in temperature, while the vessel itself will slowly cool. The rapidity of cooling will gradually diminish in a geometrical ratio, as the temperature of the canister approaches that of the surrounding bodies, and they will finally arrive at a state of dynamic equilibrium. The canister at this point does not cease to radiate, but continues to send impulses in every direction, receiving as many impulses from the surrounding bodies, (including the air,) as it sends off from its own surface.

The heat from this source possesses peculiar properties. First, it is readily absorbed by all bodies in proportion to some peculiarity of the texture of their surface, but is *wholly independent of the color;* or in other words this kind of heat, unlike light, is absorbed by light-colored substances as well as dark, and this fact would be in accordance with the hypothesis assumed, which supposes these two emanations to consist of waves of different lengths, and perhaps of slightly different form. Secondly, this kind of heat is incapable of passing by direct radiation through many media which are freely traversed by light, such as glass, alum, and many other transparent substances, while it is freely transmitted through polished plates of rock-salt, and partially through many other bodies, some of which are impervious to light. The former class of bodies is called *athermanous*, the latter *diathermanous.*

Let us now suppose the radiating body to be one which can be increased in temperature until it becomes red-hot. At a certain stage of incandescence, other rays than those described as capable of exciting heat begin to be given off along with the former, which are distinguished by different propperties. First, they tend to be absorbed by all bodies in proportion to the darkness of their color, and approximate in this respect to the property of light. Secondly, they possess a property of transmissibility without diminution, through all transparent substances, through colorless media, and in various proportions through colored media, according to the nature of the latter.

While bodies heated below redness give off exclusively rays of the first class, (though approaching in character those of the second as the temperature is increased,) incandescent bodies simultaneously give off both species.

As the intensity of heating still further increases, rays of less and less length are given off, until they arrive at the limit of the perceptibility of the sense of vision, and only render their existence manifest by chemical and phosphorogenic effects.

The following table exhibits some of the results which

Melloni obtained by experimenting with different sources of heat and different substances.

Relative absorbing power by different substances of different kinds of heat.

SUBSTANCES.	Naked flame.	Incandescent platinum.	Copper, at 75° F.	Copper, at 212° F.
Lampblack	100	100	100	100
White lead	53	56	89	100
Isinglass	52	54	84	91
Indian ink	96	95	87	85
Shellac	43	47	70	72
Polished metal	14	13·5	13	13

As an illustration of the effects of radiant heat of different kinds, we may mention the fact, long observed, of the melting of snow near the trunks of trees and other dark-colored bodies. That this effect is not due to the natural heat of the plant is evident from the fact that it is equally exhibited around the stumps of dead trees, and dark-colored objects of an entirely different character. The rays of heat from the sun, (as before stated,) possessing similar properties to those of light, are absorbed by dark substances, and freely reflected from light ones. The facets of the small crystals of snow reflect this heat almost entirely, while it is absorbed by the dark surface of the wood of which it raises the temperature, thus producing a new source of emanation. The heat however given off from the wood, is that of long waves of low intensity, which is equally absorbed by light and dark bodies; hence it enters the snow, raises its temperature, and converts it from a solid to a liquid condition. We may imitate this action by supporting at a little distance above a surface of new fallen snow a piece of pasteboard, both sides of which have been covered with lampblack, and the whole freely exposed to the sun's rays. It will be found that the melting of the surface within the shadow is much more rapid than that exposed to the direct rays of the sun. The same result may be produced by the rays from an argand lamp. Having filled a square box with new fallen snow

slightly packed, and all above the rim having been removed by means of a ruler, so as to present a uniformly plain surface, the box is turned on its side opposite the lamp, and the pasteboard interposed. In a short time the plain surface of snow will be hollowed out beneath the disk, and at the end of half an hour the cavity will be several lines deep at its centre. When the same experiment is repeated by substituting for the lamp an iron ball heated to about 400° F., the phenomena present themselves in a reverse order, that is to say, the melting of the snow would be more abundant where the direct rays impinge on the surface, than where they are intercepted by the interposed disk, and instead of a hollow, a protuberance would be produced at the centre of the shaded portion. If we substitute in this experiment for the black disk of pasteboard one covered with white lead, the heat will not be absorbed, but will be reflected as from the snow itself.

Another example of the transmission and, as it were, transformation of radiant heat from the sun is afforded in the high temperature produced by the ordinary hot-bed of a garden. The solar rays, consisting of short vibrations, readily pass through the glass cover, and are absorbed by the dark ground, the atoms of which they put into more rapid vibration, and these in turn give rise to new emanations, which consisting of long waves are arrested by the glass, and the temperature of the enclosed space is thus constantly increased. It is also on the same principle that the radiant heat of a stove does not pass out into space through the windows of a house, though a considerable portion of the radiant heat from an open fire would be lost in this way.

We may apply the foregoing principles to explain the accumulation of heat at the surface of the earth. The transparent envelope which covers the surface of our planet is not entirely diathermanous; and though it transmits freely the intense rays of the sun it stops those of the long vibrations. The surface of the earth is then in the condition of the ground under the glass of the hot-bed; it is constantly absorbing and receiving heat of high intensity, and constantly radiating heat of intermediate intensity. Let us suppose all

heat removed from the earth, and the sun suddenly allowed to shine upon it. In this case, all the rays which traversed the atmosphere and reached the earth would be absorbed. None would be radiated into space until the temperature of the surface was so elevated that the rays emitted from it could permeate the atmosphere.

The surface of the earth at first would therefore receive more rays than it gave off. Its temperature would increase and with each increase of temperature a greater number of rays would be produced of such intensity as would enable them to permeate the atmospheric envelope, and finally an equilibrium would be attained in which the rays sent off in a given time would be just equal in number to those received.

The point of temperature at which this equilibrium would take place will depend on the height and permeability of the atmosphere. If the aerial envelope offered no impediment to the escape of heat of the lowest intensity, the equilibrium would take place at so low a temperature that all bodies capable of freezing would be perpetually in a solid state. If on the other hand the atmosphere were more dense than it is, or in other words, more impervious to rays of a higher intensity than those which now pass through it, the temperature of the surface of the earth would increase until the heat given off would again be equal to that received. The new equilibrium would be permanently retained, and the whole average temperature of the surface of the globe would be elevated.

Heat from the Stars.—The temperature therefore of the surface of a planet depends upon the nature of its atmosphere, provided the heat which falls upon it is derived from a source of high temperature: now radiations from the stars are of this character, since they come from self-luminous bodies, which are probably suns of other systems. The radiations from them can therefore readily pass through our atmosphere, and excite heat vibrations in the surface materials of the earth. The intensity of these vibrations must increase until it becomes so great that the radiations produced can permeate the aerial covering, and in this way

even the heat of the stars may so accumulate as sensibly to contribute to the temperature of the earth. Though at first sight it may appear that the effect from this source must be exceedingly feeble, yet when we reflect that the heat of the stars comes from every part of the whole concave of the heavens, while that of the sun proceeds from a disk which occupies only the five-millionth part of the whole sky, we may be inclined to attribute to the stellar radiation a much greater importance than without this reflection we should ascribe to it.

M. Pouillet, of Paris, has made a series of very ingenious researches on the subject of the temperature of space, and has arrived at very unexpected results. He employed in his observations an instrument to which he gave the name of "actinometer," or ray-measurer. It consisted of a cylindrical box of polished silver, about eight inches in diameter, and five in height, enveloped in swan's-down, and enclosed in an outer cylinder, so as to prevent as much as possible the effect of the temperature of the circumambient air. The box was filled with several layers of swan's-down, so supported as not to press upon each other. In the centre of the upper surface of the open box was placed the bulb of a thermometer, the stem projecting horizontally. A cylindrical border was raised round the edge of the box, to cut off the lateral rays, and at such a height that two-thirds of the whole sky could be seen by an eye at the point occupied by the bulb. The thermometer thus enclosed was turned during the night to the zenith, and exposed to the radiation from the clear sky. The temperature of this thermometer and one exposed to the air at four feet from the ground was observed hourly.

If the heat of the surrounding air were entirely excluded from the enclosed thermometer, it is evident that it would only be affected by the radiation from celestial space, and from the atoms of the air in the column between it and the top of the atmosphere.

Of these two sources of radiation one, namely that of celestial space, would be constant and remain the same during

the whole night, as well as different nights, while the other, namely the radiation from the air, would vary from hour to hour, since it depends on the varying temperature of the atmosphere.

By obtaining a series of observations in different states of the atmosphere an assumption could be made as to the fixed temperature of space which, when subtracted from the temperature observed, would give the radiation of the column of the atmosphere.

Since it was impossible to cut off all the heat from the instrument except that which it received from the sky and air above, and since it was exposed to but two-thirds of the celestial hemisphere, some correction was necessary to reduce the observed temperature to the true one. This was found by making an artificial sky, formed of a zinc vessel about forty inches in diameter, the bottom coated with lampblack, and the whole filled with a refrigerating mixture. Beneath this the "actinometer" was vertically placed at such distances as to expose it successively to one-quarter, one-third, and two-thirds of the hemisphere; and by repeating these experiments with different temperatures of the artificial sky, it was found that if from the temperature of the surrounding air $\frac{9}{4}$ of the lowering temperature of the actinometer were taken away, the temperature of the artificial sky would be obtained, since the same ratio would obtain in the case of the real sky. In order to find therefore in all future experiments the temperature which the actinometer ought to assume under the radiation from space and the air above, it was only necessary to subtract the degree given by the instrument from the temperature of the surrounding air and multiply this by $\frac{9}{4}$. From a series of observations thus corrected, he found for the fixed part of the temperature given by the instrument, or in other words the temperature of space, a value of —142° C. or —222° F. This temperature is much lower than that obtained before from considerations of a more theoretical character. M. Pouillet however thinks that it cannot be far from the true temperature of celestial space, since a thermometer placed upon the coldest part of the earth and

exposed to the clear sky, always falls by its own radiation several degrees lower than the temperature of the air; which it would not do if the temperature of space were not lower than —60°, since as it approached that temperature at places near the pole, the extra cooling from exposure to the sky would be very little. Mr. Espy concludes, from theoretical data, that the estimate of Pouillet is near the truth.

Pouillet finds, from the data given above, that the total quantity of heat which space transmits in the course of a year to the earth and atmosphere, would be sufficient to melt a stratum of ice upon our globe of 85·28 feet in thickness. From other investigations of a similar character, which we shall presently describe, he finds that the quantity of solar heat received by the earth in the course of a year is sufficient to melt 101·68 feet of ice. From these two sources together then the earth receives a quantity of heat sufficient to melt 187 feet of ice. These results are of so unexpected an amount that though obtained by instruments and methods which are apparently unexceptionable, they have not fully obtained acceptance, and the subject is therefore still open for further examination.

Terrestrial temperature.—If the earth were exposed in space without an envelope and without receiving radiation from any source, it would sink to the zero of temperature, or that at which the atoms would cease to vibrate, and this, according to the mechanical theory of heat, would be about 500° below the freezing point of Fahrenheit's scale.

If the earth were exposed without an envelope to the temperature of space it would, according to the results obtained by Pouillet, fall to — 222° of the same scale.

With the present envelope and stellar radiation it would stand at —128°. The heat necessary to make up the actual temperature of the earth beyond this degree is due to the sun's accumulated heat under the envelope.

Pouillet has also made a series of researches on the absolute amount of heat from the sun. He used in his investigations an instrument to which he gave the name of pyr-heliometer (measurer of the heat of the sun). It con-

sisted of a flat cylindrical vessel, the top of which was of thin silver, of about four inches in diameter and six-tenths of an inch in height or thickness. It was filled with 100 grammes of distilled water, and in the middle of this liquid was placed the bulb of a thermometer with a fine bore and a long stem projecting downward in the direction of the axis of the cylinder through its lower surface.

The observations were made in the following manner: The upper surface of the vessel, coated with lampblack to render it absorbent of heat, was turned directly towards the sun, the water being kept in a state of constant agitation in order to equalize the heat. The increase of temperature received from minute to minute in the course of five minutes was noted. The vessel was then placed in the shade while its face was exposed to a portion of clear sky near the sun, and the loss of temperature from minute to minute during five minutes was again noted. A little reflection on the principles of the interchange of heat, according to which bodies are constantly radiating even while they are receiving heat from other bodies, will render it evident that in order to find the amount of temperature communicated by the sun in a minute of time we must add the loss of temperature during the shading of the instrument to the gain of temperature noted during the direct exposure to the sun, for while the instrument was receiving heat from the sun it was at the same moment radiating heat to that body. To find from the indications thus obtained the absolute amount of heat which falls on the face of the vessel in one minute of time we must make a correction for the absorption of heat by the metal, and allow for the specific heat of the water, that is, the relative quantity necessary to elevate a pound of this liquid one degree of Fahrenheit's scale. In this way the quantity of heat which falls on a given surface, (say a square foot,) perpendicular to the solar beam at the surface of the earth is determined. But this quantity is not all that would be given to the same surface were the atmosphere removed, or if the same experiment were made at the outer limits of the aerial covering of the globe. A portion of the heat is

absorbed and another portion reflected from the atoms in its passage through the air, and in the solution of the problem under consideration it became necessary to know the amount of loss from this cause. To ascertain this the experiment was made while the sun was on the meridian and at different degrees of elevation even down to near the horizon. The diameter of the earth, the approximate height of the atmosphere, or the length of the column of air traversed by the ray which passes from the zenith, and also the angle of elevation of the sun being given, the lengths of the several lines through the atmosphere traversed by the respective rays were readily calculated; and if we suppose that the amount of heat received at the outer limit of the atmosphere is invariable it is not difficult to determine the part which is absorbed. The numbers obtained by observation consisted of two quantities, a constant and a variable one; the former being the heat of the sun, and the latter the amount absorbed in passing through the different lengths of atmosphere.

From these data the amount of heat received from the sun on a square centimetre at the limit of the atmosphere, (and which it would equally receive at the surface of the earth if the air did not absorb or reflect any of the incident rays,) was ascertained to be 1·7633 units of heat in one minute of time: equivalent to 11·376 units per square inch, in the same period. It was also found that the atmospheric absorption of the rays directly from the zenith was comprised between eighteen and twenty-five-hundredths of the whole, even in cases where the sky was perfectly clear.

The quantity of heat which the sun sends to one centimetre of the earth's surface during one minute of time by its perpendicular action having been determined, it was not difficult to ascertain the total quantity of heat received by the whole illuminated hemisphere in the same time. Indeed this quantity is nearly the same as that which would fall on the plane of a great circle of the earth. From this can be readily deduced the amount of heat which would be distributed over the entire surface of the earth during a year;

and this was determined to be 231,675 units falling on each square centimetre of the whole surface. Calculating the amount of ice which this quantity of heat would melt, Pouillet obtained a thickness of 30·89 metres, or a little more than 101 feet; that is, if the total quantity of heat which the earth receives from the sun in the course of a year were uniformly distributed over all points of the globe, and were employed without loss in dissolving ice, it would melt a stratum having the above thickness.

The data given by these experiments enabled him to solve another problem which would appear even of a more transcendental character: that is, the amount of heat given off by the whole surface of the sun in a given time. For this purpose it is only necessary to consider the sun as the centre of a spherical enclosure, the radius of which is the distance from the earth to the sun;* and it must be evident that on each square centimetre of the concave surface of this vast sphere as much heat is received as on a square centimetre at the surface of the earth. If then the number 1·7633, before obtained, is multiplied by the number of square centimetres in this spherical surface the absolute quantity of heat given off by the sun during a given time will be ascertained. Or by reference to the visual angle subtended by the sun, the number expressing this quantity for each minute of time may be stated as 84,888 thermal units for each square centimetre of the solar surface.

If this quantity of heat emitted by the sun were exclusively employed in dissolving a stratum of ice, applied to the solar surface, and enveloping it on every side, it would melt in one minute a stratum of 11·8 metres thick; and in one day a stratum of 16,992 metres, or about 10½ miles.

These results cannot be considered more than approximations, though in the progress of science, they may be rendered much more precise, and may be applied to solve many problems relative to the physical phenomena of the earth and our solar system.

*The proportional amount of the entire solar radiation intercepted by the terrestrial hemisphere is 1 ÷ 2 300,000 000.

Original heat of the earth.—Besides the smaller influence of celestial space, and the governing one of the emanations from the sun, there is another source of terrestrial heat, which, though it at present produces scarcely an appreciable effect upon the temperature of the surface, was once powerfully active in effecting geological changes, and in so modifying the surface of our planet as to give rise to the diversities of surface constituting mountains, seas, and continents, which now determine the varieties and peculiarities of our present climates, and may in the future be of vast practical value in its applicability to the wants of life. We allude to the internal heat of the earth.

That the earth was once at least in a liquid condition by heat, can scarcely be doubted, when all the cumulative evidence in favor of the hypothesis is considered.

First. Self-luminous bodies are met with in every part of the visible universe, and if we follow the strict inductive process, allowing no more causes than are true and sufficient, we must admit that these bodies are intensely heated. It is therefore not impossible that the earth itself may have been at one time a self-luminous star.

Second. The surface of our moon, though it now gives little or no indication of heat, appears when viewed through a powerful telescope almost covered with the craters of extinct volcanoes; and hence we may infer that it has cooled down from a high temperature to its present condition.

Third. Every portion of the earth's crust exhibits the remains of igneous action, and the facts of geology are inexplicable on any other hypothesis than that of the past high temperature of our globe.

Fourth. On every part of the earth where the experiment has been made, starting from the point where the sun's influence ceases, there has been found an increase of temperature as we descend toward the centre, at the rate of about a degree for every fifty feet.

Fifth. On different parts of the earth's surface springs of hot water are found bursting forth.

Sixth. There are on the surface of the earth several hun-

dred volcanoes, which occasionally emit heated materials, and in some cases incandescent lava.

Seventh. The oblate form of the earth is on an average that which would be due to the rotation of a liquid mass.

From all these facts we may now safely admit as a definite theory, the hypothesis which was at first a mere antecedent probability, namely, that the earth was at one time in a highly heated state, and that its interior, even at the present moment, is still at a very elevated temperature. If we apply this hypothesis to the facts of geology as they are generalized and arranged at the present day, we have a complete explanation of the whole; or if there be any outstanding phenomena not yet included in this generalization, their number is so small in comparison to those included in it, that they may reasonably be left for the present until further discovery shall throw more light upon their character. The great principle of universal gravitation was not abandoned though at one time several facts in regard to the motion of the moon could not be referred to it. The same consideration applies to moral subjects as well as to those of science.

Equilibrium of the Atmosphere.

The aerial covering which surrounds our earth may be compared to an ocean, of which the bottom is composed of land and water, which has a definite surface above, probably agitated by tidal waves of great extent and magnitude. Although nearly eight hundred times lighter than water at the surface of the earth, yet it possesses a very appreciable weight, since a cubic yard of it weighs about two pounds, and consequently when moving with high velocities it produces great mechanical effects upon bodies subjected to its momentum.

This ocean, unlike the aqueous ones belonging to our earth, diminishes in density very rapidly as we ascend, and finds its limit at that elevation at which the repulsion of the last layer of atoms added to the centrifugal force of the earth's rotation is just balanced by the attraction of gravitation.

In order to simplify the conditions and to give precise ideas of the mechanical equilibrium of the atmosphere we will at first suppose it to be a body consisting of simple atoms, which though they obey the attraction of the earth repel each other. This repulsion increases, as we have said in our exposition of the atomic theory, with a diminution of the distance of the atoms—a fact which may, perhaps, be best illustrated by a portion of air confined by a movable piston in a tube closed at the bottom, as in the case of the ordinary fire syringe, the well known instrument used for igniting tinder by means of the condensation of a portion of air. If such an instrument be placed under the receiver of an air-pump, and the pressure of the atmosphere be removed from it, the air which is contained under the piston will expand; and if the tube be sufficiently large this expansion will continue until the repulsive energy of the atoms under the piston is just equal to the weight of the piston itself. If we now double the weight of the piston it will descend until the air is compressed into half its first volume. At this point a new equilibrium will take place between the weight of the piston and the repulsive energy of the atoms. If another addition be made to the weight of the piston it will descend through another distance, and in all cases the compression will be inversely proportioned to the weight applied; but the density of the air, that is, the weight for a given quantity increases as the bulk diminishes, and therefore in all cases of a gas the density or the number of ponderable atoms in a given space will be inversely proportioned to the pressure applied.

This fact was discovered independently by an English and a French philosopher, and is generally known by the name of the discoverers, namely, the law of Boyle and Mariotte, but perhaps more frequently it bears the name of the latter.

The same law applies to all other gases within certain ranges. In the case of atmospheric air, within the limit of experiment it appears to hold without variation, or if any, with a very minute one, when great pressure is applied in connection with a great reduction of temperature. In the

case of carbonic acid, the range of distance of atoms is much less in which this law is found; for by mechanical pressure the gas is converted into a liquid, a sudden change taking place in the intensity of the repulsion of the atoms at this point. Vapor of water, separated from the liquid which produced it, obeys the same law as that of air; but in this instance the range of atoms is still more limited than in that of carbonic acid, and with a slight pressure, and at the ordinary temperature of the atmosphere, the vapor is converted into a liquid.

The atmosphere being subject to the law of Mariotte, we shall now proceed to inquire what will be its condition of equilibrium or rest.

First. If we suppose the whole atmosphere surrounding the earth to be divided into a series of strata of equal weight, as thin as may be necessary, and separated by ideal surfaces perpendicular to the plumb line, these surfaces will rest upon each other, and be in a state of equilibrium when each part of the same stratum is of the same density.

Second. In order to a stable equilibrium, the density of each stratum must diminish from below upward.

Third. The upper stratum must be below the point where the centrifugal force, derived from the rotation of the earth, becomes equal to the weight of the air at this point.

If the first condition is not fulfilled, (that is if the equality of the density of the strata be not the same at all points,) the heavier parts will flow below those which are less dense, and buoy them up in the same manner as the heavier liquid sinks below the lighter one; and it is evident that if the upper strata were heavier than the lower ones, an unstable equilibrium would be produced which the slightest agitation would overthrow.

Lastly, if the atmosphere extended upward above the point where the centrifugal force equalled the weight of the gas, the whole atmosphere, strange as it may appear, would fly off into void space. To explain this, it is necessary to demonstrate the important though paradoxical fact which results as a logical consequence of the law of Mariotte,

that the total height of an atmosphere surrounding a planet does not depend upon the quantity of gas of which it is constituted. To prove this, let us imagine a vertical column, say an inch square at the base, filled with air of a given density extending to the top of the atmosphere. Let us suppose this column to be divided into portions an inch high throughout its whole length by movable planes, and into each one of these portions double the quantity of air to be introduced. The lowest portion, namely, the first inch, will not be enlarged by this condition; for though twice as many repellant atoms are introduced into the same space, tending to repel upward the first dividing plane, yet this plane will be pressed downward by twice the weight, because twice the number of atoms have been introduced into all the strata above.

The same reasoning may be applied to all the successive strata until we come to the very highest. On this no additional weight is placed, and it would therefore expand until the diminution of its elasticity just equals its own weight, and at this point the equilibrium will take place. If however this point should be just at the place of equilibrium where the weight of the atom would be overcome by the centrifugal force, the upper film would be removed, another would expand into its place, and another, and another, until the whole atmosphere would be withdrawn. This, as we have said, is a logical consequence of the extension of the law of Mariotte, and has been applied by Dalton and others to determine the heights of mixed atmospheres, or of atmospheres of different densities. But the height of the atmosphere is probably far below the point where the weight of the atom is equal to the force of gravity, since this may be found by calculation to be at about 5·6 times the earth's radius from the surface at the equator, or about 22,400 miles. If we suppose the column to be formed of a lighter gas, as for example hydrogen, the atoms of which have the same repulsive energy as those of air, then the column will be inversely proportioned to the density at the surface, and from this we can readily calculate the relative heights of atmos-

pheres of different gases, having different densities at the surface of the earth. These heights will evidently be inversely as the densities, or in other words the specific gravities, of the same gases under the same pressure. If the specific gravity of hydrogen be represented by 1, that of nitrogen in round numbers will be 15, that of oxygen 16, and that of carbonic acid 22, and the total heights of atmospheres of these gases will be inversely as these numbers; or if we call the height of an atmosphere of oxygen 60, then the heights of atmosphere of these gases will be as follows:

Gases.	Specific gravity.	Height of atmospheres.
Hydrogen	1	960
Nitrogen	15	64
Oxygen	16	60
Carbonic acid	22	44

In the foregoing the repulsive energy has been considered as increasing in conformity with the law of Mariotte, directly as the pressure and without regard to the increase of repulsion caused by heat; but if we suppose that the repulsion of the atoms of the lower stratum is increased by heat, they will be farther separated, and the space occupied by them enlarged. But if the heat extends upward through the whole, each of its parts will be uniformly expanded, and hence the relative height of atmospheres of different grades will not be altered by an increase of heat, provided this increase is the same in each gas. The absolute heights will however be increased $\frac{1}{490}$ part for each degree of Fahrenheit's scale above its volume at the freezing point.

In order to obtain or determine an equilibrium of the atmosphere when the natural repulsion of the atoms is increased by heat, each stratum as we ascend must at least contain the same amount of caloric. In this case, if a quantity of air be removed from a lower to a higher position, it will expand on account of the reduced pressure, and the same amount of heat being now diffused through a larger space, the intensity of its action or its temperature will fall, and

thus a reduction of sensible heat will be observed as we ascend in the atmosphere. The equilibrium we have described would not however be a stable one, and hence the upper strata of the atmosphere contain more heat per pound than the lower.

Until about the middle of the last century, the atmosphere was supposed to consist of one simple homogeneous substance, and after modern chemistry had discovered it to be a compound, the ingredients were thought to be chemically united. It was also supposed, until the researches of Dalton proved the contrary, that the vapor of water found in the atmosphere was dissolved in it, as one liquid is dissolved in another.

Dalton was the first to advance the proposition that the atoms of different gases neither attract nor repel each other; and though each offers a slight mechanical obstruction to the free motion of the other, yet if sufficient time be allowed, each will arrange itself as if the other did not exist; or in other words while the atoms of the same gas repel one another, those of different gases exert no action of this kind, and are in fact statical though not dynamical vacuums each to the other. The fundamental fact on which this theory is based is the following: If two wide-mouthed jars be placed, one on the other, mouth to mouth, the lower one being filled with oxygen or heavy gas, and the upper one with hydrogen, the lightest of all gases, and thus suffered to remain, after a short time it will be found that the two gases will be thoroughly mingled through both jars; the light gas will descend and mix with the heavier, while the heavier will in turn ascend and mix with the lighter. There will be no increase or diminution of bulk of the two gases after they have thus mingled. In order to explain the mixing of gases, three hypotheses may be assumed:

First. We may suppose that the atoms have an affinity for each other in their gaseous state. But if this were the case, from general analogy there should be a diminution of the bulk; the number of centres of repulsion would be diminished, and also the intensity of the action of each would be at least partly neutralized.

Secondly. We may suppose that the two classes of atoms repel each other, but in this case no mixture could take place; the heavier gas would remain in the lower vessel, while the lighter one would occupy the upper position.

Thirdly. If we suppose the atoms of the two gases have no action on each other, but are free to obey their own repulsions, then the atoms of each gas will expand into the void space of the interstices of the other, and the diffusion indicated by the experiment will be produced.

It follows from this hypothesis that the bulk of the mixture should remain the same before and after the mingling takes place. Let us suppose each vessel to contain a foot of gas, and that the repulsive energy is sufficient to sustain a weight of 15 pounds to the square inch; and let us suppose the interior of the vessel containing the hydrogen is a vacuum. Then it is evident that the oxygen in the lower vessel, being relieved from the pressure of the atmosphere, will expand and fill both vessels, and by the law of Mariotte, its elastic force or repulsive energy will be reduced to one-half or 7½ pounds to the square inch. The same will take place with regard to the hydrogen. It will expand downward and fill both vessels, and its elastic force will be reduced to one-half or to 7½ pounds to the square inch. If therefore the gases are vacuums to each other, they will each expand into the other and form a mixture of two gases, the pressure of each of which against the sides of the vessel will be 7½ pounds to the square inch, and consequently the whole pressure will be 15 pounds.

The theory of Dalton is in exact accordance with all the facts, though it may be difficult to conceive of atoms, such as those of oxygen and hydrogen, as being without action on each other particularly when highly compressed. Indeed, Mr. Dalton in the latter part of his life was inclined to refer this seeming want of repulsion to the fact of the different sizes of the atoms, or in other words to the difference in the spheres of their repulsive energies. If two classes of atoms were thus mingled with each other, it is evident that they could not be in equilibrium until the one was generally

diffused through the other; this would give a ready explanation of the diffusion of the two gases through each other in close vessels. But it does not seem to us to be applicable to the explanation of free atmospheres co-existing on the surface of the earth, as appears to be the case, particularly with reference to the gases and aqueous vapor of the atmosphere.

I have dwelt upon this point because very erroneous ideas are frequently entertained as to the theory of Dalton, which, whatever may be its truth, has had a very important bearing on the progress of meteorology. By one class of writers on the subject it has been the basis of all investigation, and by another it has been too much neglected. All our hygrometrical calculations relative to the amount of water in the air rest upon it. While there remains but little doubt that if the air, as a whole, were at rest, and sufficient time were given for the establishment of an equilibrium, the several ingredients would arrange themselves in accordance with this theory; yet, since the atmosphere is constantly agitated with currents, and diffusion is carried on more rapidly through this agency than that from the self-repulsion of the atoms, we can only suppose that there is merely a constant tendency (particularly in the lower strata of the atmosphere) to assume the statical condition indicated by the theory.

Composition of the Atmosphere.—At the level of the sea and at all accessible heights our atmosphere principally consists of a nearly invariable mixture of two permanent gases, oxygen and nitrogen, and a number of variable substances, of which we enumerate carbonic acid, nitric acid, ammonia, hydrogen, mineral powders, animal and vegetable matter, odoriferous substances, and above all a considerable quantity of water in a state of invisible vapor, and that of partial condensation in the form of cloud. Indeed, it must be a reservoir of all the emanations which arise from the decomposition of animal and vegetable matter, and which are given off from all substances in minute quantities under the application of heat. Though the variable portions of the atmosphere form but a small percentage of the whole mass, yet they exert an important influence on animal and

vegetable life, and deserve the special attention of the agricultural chemist.

Analysis of the Air.—But before proceeding to give an account of these, it may be well to pause here for a moment to describe the simplest method by which the constitution of the air may be approximately analyzed. For this purpose we introduce into a large glass vessel filled with ordinary air a small quantity of limpid lime water, or better still, baryta water, and having closed the vessel agitate the liquid. All the soluble substances, including the carbonic acid, will be absorbed. The latter will unite with the lime or baryta water and form insoluble carbonates, which may afterwards be separated from the water, dried and weighed, and the amount of carbonic acid thus determined. To obtain the amount of vapor in a given quantity of air the latter is drawn through a tube containing chloride of lime, a substance which has a great affinity for moisture. The increase of weight found after the process will indicate the amount of water in the portion of air submitted to the experiment. The volume of this air may be readily ascertained by attaching the tube containing the chloride of lime to the upper part of a vessel, say a cubic foot in capacity, filled with water, from which the liquid is suffered to run out by an orifice at the bottom; an equal bulk of air will enter through the tube containing the chloride, and when all the water has run out, the vessel will be filled with air, or in other words, one cubic foot of the moist atmosphere will have passed through the drying tube. The quantity of aqueous vapor is more variable than that of the carbonic acid.

After having separated the water and carbonic acid, in order to ascertain the amount of oxygen and nitrogen in a cubic foot of air, we burn in the mixture a piece of phosphorous, which combines with every atom of the oxygen, forming a soluble substance called phosphoric acid, which is absorbed by the water, leaving the nitrogen in a separate state. Other and more refined methods are frequently employed, but this will serve to indicate in a general way the mode in which the results are obtained. In this manner,

we find that the atmosphere consists of 20·01 parts of oxygen to 75·29 of nitrogen in volume, or 23·01 parts, by weight, of oxygen and 76·39 of nitrogen. These numbers are not precisely those which would result from a chemical union, as was at first supposed, namely, one volume of oxygen and four of nitrogen. They are not also entirely invariable, but are found to differ slightly at different places at the level of the sea. Observation has not shown any appreciable variation from year to year, though it is not improbable that during the geological periods changes have taken place in its proportions as well as in its amount. The quantity of carbonic acid is found, by the mode we have described, to vary from the $\frac{4}{10000}$ to $\frac{6}{10000}$ of the weight of the whole.

Oxygen, as we have seen in the exposition of the atomic theory, is a very energetic element widely diffused through nature, and performs an important part in the transformations of inert matter into plants and animals, and back again into carbonic and other inorganic compounds. The nitrogen also is an important element in vital economy, and is associated with all the most instable organic compounds. Its atoms appear to exert a great repulsive energy on each other; and hence, when confined in a solid state by surrounding atoms of other substances, the slightest jar will overturn the instable equilibrium, and produce a violent explosion.

Carbonic acid is a transparent substance that is produced when charcoal is burnt in air or oxygen, and is composed of one atom of the former to two of the latter, or three parts of one to eight of the other by weight. It furnishes the carbon of the plant, and though it exists in small quantities in the atmosphere, animal and vegetable life could not be continued on the surface of the globe without it. The quantity of carbonic acid contained in the air varies between the hours of night and day, the quantity being at its maximum towards morning, and its minimum towards the middle of the day. In this respect it follows a law analogous to that of the heat and moisture of the atmosphere. A part of this variation may be referred to the absorption of carbonic acid

by plants during the day, though this cannot be the principal cause; a more efficient one is probably the varying quantity of moisture, which may serve as a kind of vehicle for its transportation to and from the ground. There is also a great difference in the amount of carbonic acid in different places, perhaps in different countries, and it is possible that a part of the variations of fertility, the other conditions being the same, may in some cases be referred to this cause. We find, from experiment, that vegetation is favored by the increase of this ingredient until, according to Saussure, we arrive at the proportion of eight parts to one hundred, which is eighty times more than the ordinary quantity existing in the atmosphere. The same portion would entirely extinguish the life of the red-blooded air-breathing animals. It is on this fact that some geologists have founded the hypothesis that the luxuriant vegetation which existed on the earth during the coal period was due to an atmosphere charged with carbonic acid, and the amphibious character of the animals existing at that period would seem to favor this supposition.

M. Chevandier has shown that one square mile of forest land produces annually 441 tons of fixed carbon in the wood, (*Comptes Rendus*,) and Liebig increases the quantity to as much as 504 tons to the square mile. The same author also shows that all other vegetable productions yield nearly the same quantity of carbon to the square mile. Now a prism of air extending to the upper limits of the atmosphere, and having a base of one square mile, contains 4,260 tons of carbon, from which it results that the annual consumption of carbon by thrifty vegetation amounts to about one-ninth of all the carbon of the atmosphere which rests upon it. (Gasparin; vol. II.)

From this it might at first sight appear that the carbonic acid of the air ought rapidly to diminish, and in a few years to be entirely exhausted; but, as we have seen, the carbon thus extracted is not lost to the air, but lent as it were to the organized matter of the globe; for by the process of combustion and decay an equal amount of the same substance is

restored to supply the place of that previously abstracted, and the whole quantity of carbon in the atmosphere remains nearly the same from age to age, the measurable variations being only perceptible during the lapse of the ages which constitute a geological period. When we consider however the great amount of coal consumed at the present day in the mechanical arts and locomotion, it would appear that the amount of carbonic acid is increasing in the atmosphere; but when we compare with this the improvements made in agriculture, and the stimulus thus afforded to the growth of plants and animals, the effects of these artificial conditions would apparently nearly balance each other. There is another source of abstraction of carbonic acid from the atmosphere, namely, that which takes place through the agency of animal life in the production of coral; but this again may be probably balanced by the carbonic acid emitted from the various active volcanoes of the globe. We do not however by these remarks attempt to establish the fact that in all parts of nature there is an exact compensation, and that our globe has always remained in the state in which it now exists, but that the great changes which affect our planet are exceedingly gradual, and the conditions may be considered constant during the age of individuals, or even of nations.

Should the carbonic acid of the air sensibly increase over the limits before mentioned, the vegetation of the earth would, as we have seen, become more luxuriant, and animal life degenerate into a lower type. If on the other hand, the carbonic acid should be diminished, the reverse would probably take place, vegetable life would become less, and animals would either correspondingly diminish in number, or they would assume a higher type. M. Flourens supposes that the amount of organic life on the surface of the globe has remained the same through all periods, though exhibited under different forms, but this would be dependent upon the permanency of the amount of organizing force from the sun.

Saline matter in the atmosphere.—Air from the surface of the ocean contains a portion of the saline ingredients which in positions near the sea, and in some cases further inland,

produce a marked effect upon the character and condition of vegetation. Dr. Dalton found, at Manchester, one part of salt in one thousand parts of rain water. Brandes found in rain water, in Germany, besides common salt, chlorate of magnesia, sulphate of magnesia, carbonate of magnesia, chlorate of potassium, sulphate of lime, oxide of iron, oxide of magnesia, and salts of ammonia, the greatest part of these being ingredients of sea-water. This explains the fact that certain plants do not grow luxuriantly near the ocean unless screened by a fringe of trees or houses, or protected in some other way. Near the ocean, a number of garden plants cannot be made to grow unless placed near a fence which intercepts the wind from the ocean. We might infer from this that the saline matter is carried mechanically by the air, and not diffused through it, as in the case of vapor. We are informed by Mr. Browne that a gentleman at Nahant has succeeded in raising pears to perfection by protecting the trees on the ocean side by a high brick wall, perforated at intervals with comparatively small openings, sufficient however to keep up the ventilation.

Mineral matter in the atmosphere.—There is also constantly diffused through the air a considerable quantity of mineral substances, in a state of impalpable powder. This is carried up by the ascending columns of air which are constantly rising under the varying heat of the different portions of the ground due to the influence of clouds and the various conditions of the surface, and is brought down in the rain which falls in the beginning of a shower. The presence of this material at all times, is rendered evident when a ray of light enters a small hole in the window shutter of a darkened room. By some, it has even been conceived to be an essential ingredient of the atmosphere. The amount of this is much greater than we might be led by casual observation to suppose. It falls upon the decks of vessels in mid-ocean, and forms dry clouds, which were observed by Prof. Piazzi Smyth, at the height of several thousand feet, upon the side of the Peak of Teneriffe.

Its constant presence in the atmosphere furnishes an explanation of the occurence of a minute quantity of mineral matter in the composition of certain plants which is not found in the soil in which they grow.

Pollen of plants.—At certain seasons of the year, the pollen of the pine tree and other plants is carried to immense distances, and after a thunder-storm is often found on the surface of water in our rain casks and from its yellow color is frequently mistaken for sulphur.

Ozone.—Another substance which of late years has been discovered in the atmosphere by the indefatigable labors of Prof. Schönbein, the inventor of gun-cotton, is known by the name of "ozone," which is supposed from all the researches made upon it to be oxygen in a peculiar condition, in which its affinity for other substances or combining power is highly exalted. When a stream of frictional electricity is made to flow from the point of the prime conductor of an ordinary machine, a peculiar odor is perceived, due as is supposed to the oxygen of the air assuming an altered condition, and hence it has been inferred that ozone consists of oxygen with an extra dose of electricity.

M. Clausius however has advanced another hypothesis which appears to be in accordance with other facts, namely, that an ordinary atom of oxygen, of which the atomic weight is eight, is in reality a molecule composed of two atoms, and that under the influence of electrical repulsion these atoms are separated, and in the unneutralized affinity, consequent upon this separation, the increased avidity of combination is evinced.

Whatever be the nature of ozone, it is certain that it possesses great powers of combination with many other substances, and thus tends to produce chemical effects. It is probably produced on a large scale in the atmosphere, on the same principle by which it is obtained in the laboratory, namely, by the electrical discharge in the form of lightning from the clouds.

The test for ozone consists of one part of iodide of potassium, ten parts of starch, and one hundred parts of water,

boiled together for a few minutes. A thin coating of this preparation applied to writing paper with a brush, being exposed to an atmosphere containing ozone, is rendered blue from the evolution of the iodine. In order to bring out the blue color distinctly, it is necessary to dip the paper in pure water.

Besides the action of the electrical spark, ozone may be produced by the action of phosphorus on atmospheric air, provided moisture is present. It is also produced in the gas evolved in the galvanic decomposition of water. But by whatever process obtained, it always presents the following properties:

First. It is a gaseous body of a very peculiar odor, approaching that of chlorine when intense; when diluted, it cannot be distinguished from what is called the electrical odor.

Second. Atmospheric air strongly charged with it renders respiration difficult, causes unpleasant sensations, and by its action on the mucous membrane produces catarrhal affections. It soon kills small animals and undiluted must be highly deleterious to the animal economy.

Third. It is insoluble in water.

Fourth. It is a powerful electro-motive substance.

Fifth. It discharges vegetable colors.

Sixth. At common and even low temperatures it acts powerfully upon metals, producing the highest degree of oxidization of which they are susceptible.

Seventh. It destroys many hydrogenated gaseous compounds.

Eighth. It produces oxidizing effects upon most organic substances.

But the question of the greatest general interest regarding it is a physiological one. It is not found in places abounding in miasma, and from its energetic powers of combination it is thought to decompose the organic molecules of which this effluvium is supposed to consist, and hence observations in regard to it are highly desirable.

Dr. Smallwood, near Montreal, who has made an extended

series of observations upon ozone, concludes that its presence in the air does not depend upon temperature but moisture. He has observed traces of it when the thermometer was at 20° F. below and at 80° above zero. But in general it was present in large quantities during the fall of rain and snow, which may account for its greater prevalence near the sea-shore than elsewhere. It appears to exist in great quantities in dew, and to this fact has been attributed the remarkable rusting effect produced on iron when exposed to this form of precipitation of water.

Malaria, or miasma.—In certain places, there is diffused through the air an exceedingly minute quantity of a substance which has a powerful effect on the human system, and frequently offers in such districts a serious obstacle to the cultivation of the soil. It is this which gives rise to intermittent fevers and perhaps to maladies of a more malignant character. This substance is found in marshy and low places where animal and vegetable matter of an aqueous character is in a state of decomposition, but the winds which pass over these places transport the malarious effluvia to a distance and thus render whole tracts of country unhealthy.

The corpuscules of this substance appear to adhere to the molecules of water, and are elevated with the latter by the ascending currents of air to heights which vary in different countries. Around the Pontine marshes, in Italy, the malaria disappears at the height of from seven hundred to one thousand feet, while in South America, according to Humboldt, it is found at an elevation of three thousand feet; usually however its effects are exhibited with intensity at a much lower elevation than that first mentioned. It is also observed that humid air which transports miasma is deprived of this noxious material in passing through trees, and that in many cases, in the same neighborhood, a screen of foliage is sufficient to produce a marked difference between two places otherwise similarly situated. Double screens of fine gauze also placed in the windows of sleeping rooms answer a similar purpose, and should be resorted to in all cases as a precaution wherever there is danger of disease

from this cause. It is probable that the diffusion of malaria in still air, as in the case of vapor, is exceedingly slow, and hence anything that tends to interrupt the current will much retard its transmission. It is asserted that in some cases near the focus of emanation it is less deleterious than at places at a considerable distance. It would appear from this to ascend vertically with the columns of heated air and to be afterwards wafted horizontally to a distance, and there impinging on the first elevation produces its effects; or perhaps this opinion has arisen from the screening influence of objects near the source.

Miasma in perfectly dry air is in such small quantities as not only to be inaccessible to the investigation of science, but also insufficient to seriously affect human life. It is otherwise however in air cooled by the radiation of the evening and night. It appears then to be precipitated into the lower strata of the atmosphere with the mass of humidity with which it is probably connected, and when this is again evaporated at sunrise, it carries up with it the miasma in its ascending movement. At this time it is taken into the system by swallowing, respiration, and possibly by absorption through the pores of the skin, in sufficient quantities to manifest its deleterious effects. In malarious districts therefore caution should be taken against exposure to the evening precipitation and morning evaporation of the humidity of the atmosphere. Ground which has been a long time under water retains during a series of years the property of emitting the effluvia. The virgin soil in which decaying vegetable matter has accumulated for years, when first exposed to the action of the air by the labor of the pioneer, gives off a large amount of malarious effluvia; care should therefore be taken in the settlement of a new country not only to select a proper location, but also to protect the houses by a border of trees, particularly on the side against which the prevailing wind impinges. And it is to be regretted that good taste, as well as the comfort of an agreeable shade, does not more frequently induce the husbandman to spare some of the original products of the forest which are found near

the spot on which he erects his dwelling. It is also stated that plants in active vegetation, as in the case of sunflowers, absorb deleterious effluvia; but whether this effect is produced independently of the screening we have mentioned has not yet been settled. In the fertile regions of the tropics where heat and moisture abound—for example, the valley of the Amazon—and where vegetation is luxuriant, the malarious effluvium is at its maximum; while in dry countries with less vegetable life, such as those west of the Mississippi, it is not found. Nature thus is not indiscriminately benevolent to civilized man; in his uncivilized condition different races are confined to different districts, and the influences which affect one are inoperative on the other. It is only by investigating the causes of these differences, and thus in some cases arriving at the means of controlling them, that the civilized man becomes a citizen of the world, and within certain limits is enabled to overcome the natural enemies to which in his primitive ignorance he is exposed.

The difficulty of investigating the nature of miasma has induced some to believe its effects due to variations of temperature and moisture; but this is not sufficient to explain all the phenomena, as places very different in this respect vary greatly in their sanitary condition. The quantity of material (whatever it may be) which constitutes malaria is too minute to be immediately detected by the eudiometer, the instrument usually employed to analyze air. M. Moscati, in order to collect it in considerable quantities, employed a glass globe filled with ice, on the surface of which the aqueous vapor of the atmosphere was constantly precipitated. He found that the water thus collected in infected places was of a white color, inodorous, slightly alkaline, and after standing a short time lime-water and acetate of lead produced in it a light precipitate. It contained animal matter, ammonia, and chlorate and carbonate of soda. The effect of this water upon animals has not (so far as we know) been tested, though it is said that sheep which feed upon grass covered by the morning dew in infected districts are subject to peculiar maladies.

The presence of organic matter may be detected in the process just described by dropping into the water a little sulphuric acid and by afterwards evaporating the fluid we will obtain traces of carbon. If the experiment, for example, be made in a slaughter-house, comparatively a large amount of this substance will be obtained; and yet from abundant observation it is known that the animal effluvia to which the butcher is constantly exposed are not of a morbific character, since the followers of this occupation are proverbially healthy. It would appear from this fact that the hurtful miasma is of vegetable not of animal origin. That collected by Regnault had the odor of burnt plants when incinerated. The same investigator asserts that a marshy odor does not always indicate feverish infection, and that in malarious districts it was above all to be feared at times when the air appeared pure and inodorous. From all the facts then, it appears most probable that the substance called miasma is an organized body, endowed with life, and first generated in the decomposition of aquatic vegetation; that its introduction into the circulation of animals is a real innoculation affecting especially the nervous system; finally, that when it commences itself to decay in the open air it ceases to be deleterious, though it gives rise to disagreeable odors. This investigation opens a wide field for chemical research, to which the later improvements in the art of analysis may perhaps be successfully applied. Whatever may be the cause of the disease spoken of experience has indicated the following precautions for those exposed to its influence:

1st. In malarious districts, going out before the dew has evaporated, should be as much as possible avoided.

2d. Before exposure to the morning air breakfast should be taken, or some slightly exciting drink, such as coffee or tea, rather than spirits. The former produces a healthful exhilaration, which prevents an attack of the miasma, while the re-action which succeeds the exhilarating effects of the latter tends to favor the absorption of the poison.

3d. Flannel garments should be worn next to the body, as these tend to stimulate the skin and prevent the deleterious effect.

4th. The use of disinfectants, though perhaps less energetic in destroying miasma than in decomposing odors, should not be entirely neglected: and for this purpose a small quantity of chloride of lime may be found beneficial. It is said that the flashing of gunpowder in a room answers the same purpose.

5th. Screens of trees should be planted to interrupt the damp and warm wind from the focus of the emanation.

6th. During warm weather, when ventilation is more necessary, the doors and windows should be provided with screens of fine gauze.

7th. Boiled water should be used in preference to any other, or pure rain water, or that which has fallen some time after the rain commences, to which add a small portion of vinegar or acetic acid.

8th. In cool evenings of summer, the dampness of the house should be dissipated by a blazing fire upon the hearth.

It appears that the malarious influence is produced at a certain temperature, and that it is favored in marshy places by the heating of the water in shallow pools. It has been recommended to divide such places by deep parallel ditches or narrow canals at right angles to the direction of the prevailing wind, the earth being thrown up on the side in the form of dykes, which are to be planted with rapidly growing trees or large shrubs. The ditch collects the water in too large bodies to be much heated, and this liability to become warmed is further lessened by the shade of the trees. The latter also serve as a series of screens to intercept any malaria which may arise.

Nitric Acid.—If sparks of electricity are passed through a tube containing atmospheric air, the oxygen and nitrogen, which do not combine under ordinary circumstances, will chemically unite and form nitric acid. This union is supposed to be the result of the production of ozonized oxygen, which promply unites with the nitrogen on account of its increased combining energy. The nitric acid thus formed combines with ammonia, which is also found in the atmosphere as an original though a variable constituent, and forms

nitrate of ammonia. To the atmosphere is also probably due the nitric acid which forms the nitrate of lime, from which the nitrate of potash, the principal ingredient of gunpowder, is produced in the soil containing the base. We have in this instance another confirmation of the conservation and transformation of power. The discharge of the electricity in the heavens expends a portion of its energy in producing a change in the condition of oxygen which in its turn attracts and imprisons (as it were) a portion of nitrogen—a substance which of all others, appears to possess the greatest repulsive energy, and the violent breaking loose again of this from its combination exhibits its power in the explosion which ensues. In this way the bolt of Jove may be said to be partly transformed into that of Mars, and the thunder of war to be but a reverberation of that of the heavens.

Odors.—The observations which have been made during the photographic process have revealed the fact of the existence in the air of the vapors of metals and other substances which though so minute as to have escaped particular attention are yet sufficient to interfere materially with the operations necessary to the production of perfect pictures. Almost all metals heated to redness give off effluvia perceptible by the sense of smell.

The diffusion in the air of the odoriferous principle of plants and other substances is a subject worthy of more attention than it has yet received. The wide diffusion of an almost infinitesimal quantity of matter in these cases may well excite our astonishment. A single grain of musk has been known to scent a room for twenty years, and without apparent reduction of the original material. To produce this result, the minuteness of the atoms must be beyond the conception of the imagination. From the influence which chlorine has upon animal and vegetable odors, it is probable that hydrogen is an essential part of their composition. The atmosphere itself, when pure, is inodorous; but the absence of perceptible odor may be due to the fact that our sense of smell ceases in some cases to indicate an odor after having been for a certain time subjected to its in-

fluence; for example, the nauseous effluvium which arises in some processes of the arts becomes often insensible to the operator, and the same may be said in regard to the effect of animal effluvia on the inmates of crowded and ill-ventilated houses. The sense of smell, like our moral faculties, thus becomes blunted by misuse or improper association.

Matter in the aeriform condition is generally transparent, though different gases exhibit occasionally different colors; even the atmosphere possesses this property in a slight degree, as is evident in the fact of the slightly blue appearance of distant objects.

From all that we have said, it appears that the aerial ocean, like the aqueous one, is a vast reservoir, principally composed of two ingredients of nearly constant proportions, and a number of adventitious materials which in some cases, though in very minute quantities, have a marked influence on animal and vegetable life. There is however another variable ingredient, (previously alluded to in a general way,) which by its production and condensation, is the agent to which nearly all the fitful variations in our atmosphere are to be ascribed. I allude to the aqueous vapor of the atmosphere. But before proceeding to consider this, it will be necessary to treat more fully of some of the principles of heat and its influence on the climates of the earth.

Maxima and Minima of Temperature.—A certain degree of heat is necessary to give mobility to the sap of plants, and this differs in each species of plant. Vegetation is accelerated and becomes luxuriant, provided it is furnished with a corresponding amount of humidity to compensate for the evaporation as we increase the quantity of heat. It is therefore important to determine the average amount of heat in different places; but for this certain precautions are indispensable. It is not the direct heat of the sun that we at first wish to ascertain, but that of the air. Hence it is necessary to suspend the thermometer to a badly-conducting body, and the instrument itself should not have so great a volume as would prevent its readily taking the temperature of the atmosphere. If the bulb is large and the stem small,

the degrees may readily be divided into small fractions; but in this case the thermometer will fall behind in its indications, since if the temperature be increasing, some time must elapse before the instrument can arrive at this new condition; and in case it be falling, a similar tardiness will be exhibited. If on the other hand the bulb be very small, the degrees will be of less length; but since there is little of the fluid to be heated or cooled, it will more readily take the temperature of the circumambient air. For determining however the mean temperature of a place, the thermometer should not be too small, since in that case it will be more easily affected by the heat of the body during observation, and at the same time it may be affected by an accidental or fitful stream of air, and thus give too high or too low an indication. One of the ordinary size in which the bulb is about half an inch in diameter, is preferable.

For a similar reason the thermometer ought not to be suspended in immediate contact with a large solid conducting body, for example a stone or brick house, since this will retain the effects of a term of heat perhaps for several hours after the temperature of the air has changed. It should be suspended from an imperfectly conducting material, such as wood, and so situated that the air may circulate around it on every side. It should also be screened from the direct radiation of the sun, and from the reflection of surrounding bodies; for if this be not done it will indicate the average of all the impressions received, and not simply the temperature of the air. The thermometer therefore ought to be placed in the shade on the north side of the house, but a few feet above the level of the ground, in an unobstructed place; and indeed it has been recommended to suspend it between two large parallel horizontal discs of wood, which will protect it from the earth below, the sky above, and every influence except that of the stratum of air in which it is situated. Instead of this however, we may enclose it in lattice-work, easily permeated by currents of air, and painted white on the outside to reflect back the more intense rays of heat which may accidentally reach it.

If our instruments consist of a maximum and a minimum self-registering thermometer, exposed to the air in the way we have indicated, it will be sufficient in order to obtain the average temperature of the day approximately, to note the temperature of each but once in twenty-four hours. If we then add together the maximum and minimum, and divide the sum by two we shall have approximately the average temperature; but this is not precisely the quantity required for meteorological and agricultural purposes, or that which enables us to judge of the heat of different days or different periods, since the thermometer may at different times of the day be suddenly elevated or depressed and not reach its maximum and minimum gradually, as is usually the case.

To determine these points with more precision, and the average temperature of the air during the day, we must observe the thermometer at very short intervals; for example every quarter of an hour. If we add these into one sum and divide by ninety-six we shall have the mean or average temperature of the day. Before division however caution is to be observed in combining the observations taken in winter, or when the temperature sinks below zero, to subtract the sum of the observations with the *minus* signs from the sum of those with *plus* signs.

In running our eye down the column of a series of observations of this kind, we can mark not only the maximum and minimum temperature for the day, but also the time at which they occurred. If we continue these observations, during the month of thirty days for example, we shall obtain thirty maxima and as many minima, and an equal number of mean temperatures. If we now add these thirty observations of the same kind together, and divide by the number thirty, we shall obtain the maximum, the minimum, and the mean of the month. Similar observations continued throughout the year and thus combined will give us the mean of all the maxima, of all the minima, as well as the general means of all the three hundred and sixty-five or three hundred and sixty-six days of which the year may be composed.

There is still another way of combining these observa-

tions. We may take, for example, the mean of all the temperatures of mid-day for the month or the year, or of any other hour of the twenty-four, and from this obtain the mean temperature of all hours of the day and night. Finally, instead of limiting our observations to a single year we may extend them to a series of years, in order to determine more accurately the mean temperature of a given place, all accidental variations of particular years and seasons being reasonably supposed to balance each other. It is by this admirable invention of extended averages that order and regularity are deduced from phenomena which appear to be under the influence of no fixed laws, and that we are enabled to arrive at permanent and constant quantities, by eliminating those which are irregular and variable.

A series of observations continued during the day and night through a number of years, or even a single year, involves an amount of labor which few men of science can afford to bestow upon meteorology; and few have the industry and perseverance necessary to so prolonged and tedious an effort. This task however has been performed under the direction of several persons in this country, namely, Prof. Dewey, in Massachusetts; Capt. Mordecai, at the United States Arsenal, near Philadelphia; Prof. Bache, at Girard College, Philadelphia; Prof. Snell, at Amherst; and Col. Lefroy of Toronto; not to mention the names of a large number of persons who have executed the same work in Europe. Could it be repeated in a number of different places in this country, the results would be of essential importance in correcting the ordinary observations made at fixed hours of the day.

To illustrate these observations and the uses to which they may be applied, we shall select a series made since 1816, at the Observatory of Paris, by M. Bouvard, at six different epochs of the day, namely, from nine o'clock till mid-day, and from three to nine in the evening, the other hours being given by interpolation:

Hours.	Temperature.		Hours.	Temperature.	
	° C.	° F.		° C.	° F.
Midnight.	8·5	47·30	1 P. M.	14·1	57·38
1 A. M.	8·1	46·58	2	14·47 max.	58·05
2	7·7	45·86	3	13·91	57·04
3	7·4	45·32	4	13·4	56·12
4	7·13 min.	44·83	5	12·8	55·04
5	7·5	45·50	6	12·2	53·96
6	8·2	46·76	7	11·6	52·88
7	9·2	48·56	8	10·8	51·44
8	10·3	50·54	$8\frac{1}{3}$	10·67 mean.	51·21
$8\frac{1}{3}$	10·67 mean.	51·21	9	10·19	50·34
9	11·21	52·18	10	9·7	49·46
10	12·1	53·78	11	9·1	48·38
11	12·9	55·22			
Noon.	13·5	56·30	Mean......	10·67	51·21

From this table we see, first, that the annual mean temperature at Paris is 10°·67 C., or 51°·21 F. Second, that the minimum is near four o'clock A. M., and the maximum about two o'clock P. M. Thirdly, which follows from the last, the air is heated during ten consecutive hours, and is cooled during fourteen hours. Fourth, that we fall into a small error in deducing the mean temperature from the maximum and minimum of the day, the true mean being 10°·67; while the other is 10°·8. Fifth, that the mean temperature is at 8 h. 20 min. in the morning and 8 h. 20 min. in the evening. From this it is evident that, in order to find the mean temperature of the year, it is sufficient to observe the thermometer each day at twenty minutes past eight in the morning and at twenty minutes past eight in the evening; but if our object is to obtain the mean for each month of the year, it is necessary to change the hour in question, since it is found that for January, 1 o'clock A. M. is the proper hour, for July, 7 o'clock A. M.; and for all the other months, intermediate hours. The epoch of the mean experiences similar changes in the evening.

Having discussed the variations of the temperature of different hours, it now remains to speak of the monthly variations. From twenty years' observations at Providence, Rhode Island, the following result has been obtained by

Professor Caswell, of Brown University. This gentleman has made a series of observations extending through upward of a quarter of a century, and has presented the whole to the Smithsonian Institution for publication.

Temperature of Providence, Rhode Island; by Prof. A. Caswell.

Years.	Months.												Year
	Jan.	Feb.	Mar	Apr	May	Jun	Jul.	Aug	Sep.	Oct.	Nov	Dec.	
1838	32·5	17·9	35·1	40·8	53·5	68·2	75·0	71·0	61·4	47·2	35·3	25·8	47·0
1839	26·3	27·9	34·9	46·7	56·0	62·2	71·7	67·9	61·1	51·5	37·3	30·6	47·8
1840	18·6	32·9	36·0	47·5	57·3	67·6	72·2	70·9	58·5	51·3	39·2	27·7	48·3
1841	30·5	25·1	35·1	42·2	54·1	68·6	70·0	69·2	63·2	45·8	37·3	32·7	47·8
1842	30·8	34·4	39·7	46·3	53·4	64·2	71·8	68·3	59·3	50·9	38·7	30·2	49·0
1843	34·2	22·4	28·7	45·3	54·4	64·3	68·8	69·8	61·3	49·3	37·6	30·9	47·2
1844	20·2	28·2	36·3	50·6	58·5	64·6	68·4	67·8	59·6	49·9	39·1	32·2	47·9
1845	30·7	28·5	41·3	44·6	54·2	64·8	69·0	68·2	57·5	50·7	42·5	24·9	48·1
1846	27·3	21·7	39·4	46·3	53·2	60·7	67·5	71·2	66·0	50·2	44·6	29·8	48·2
1847	29·3	28·7	32·3	43·0	54·3	65·6	71·3	68·7	62·3	49·8	45·8	39·6	49·2
Mean of 10 years	28 0	26·8	35·9	45·3	54·9	65·1	70·6	69·3	61·0	49·7	39·7	30·4	48·1
1848	32·3	27·4	33·3	46·8	58·8	66·2	70·2	79·4	59.7	51·2	37·8	37·3	50·0
1849	24·6	22·3	37·0	43·7	54·2	67·5	70·6	69·9	60.5	50·9	47·3	31·2	48·3
1850	30·5	32·2	34·0	43·1	52·3	67·2	72·4	67·8	60·7	52·9	43·5	29·3	48·8
1851	29·8	32·1	38·5	46·3	56·4	64·2	70·6	67·7	61·0	53·7	36·9	25·5	48·5
1852	23·9	28·6	34·7	41·8	57·1	67·7	72·4	66·6	62·6	52·4	39·7	37·8	48·8
1853	28·4	30·5	36·0	44·4	57·0	66·9	70 8	69·2	62·5	49·4	42·6	28·6	48·9
1854	26·4	25·6	33·1	42·9	57·7	65·9	72·9	68·6	61·4	52·9	40·7	26·5	47·9
1855	30·0	21·1	32·6	44·1	54·7	65·3	72·9	67·9	61·9	52·4	42·0	32·3	48·1
1856	19·3	22·7	27·8	46·8	53·5	67·7	72·1	69·8	63·2	50·2	39·4	25·5	46·5
1857	16·3	32·7	32·2	41·0	52·8	62·0	69·9	66·8	60·3	50·5	42·3	34·6	46·8
Mean of 10 years	26·1	27·5	33·9	44·1	55·4	66·1	71·5	69·4	61·4	51·7	41·2	30·9	48·3
Mean of 20 years	27·1	27·1	34·9	44·7	55·2	65·6	71·0	69·3	61·2	50·7	40·5	30·6	48·2

It appears from this table that the coldest month is January, and the warmest are July and August, which are nearly the same. The mean temperatures of April and October are nearest to the mean of the year. In the two periods of ten years each, at Providence, the difference between the mean temperatures is but two-tenths of a degree; the differences also between the mean temperatures of the several months

in the two decades scarcely differ a degree in the whole series. If the times were further extended the agreements would probably be closer, the instruments remaining the same. These facts illustrate the truth of what we have previously said relative to the deduction of definite results from the most complex and variable elements, and the permanency of the mean temperature of a given position; the sum of the variations consisting in oscillations on either side of the mean, which in the aggregate neutralize each other.

It is known from extended observation that the same weather exists at the same time over a large extent of country. For example, during a cold winter, it is comparatively cold over the whole of France; and in the State of New York, though the temperature be different in different places, a cold January will be cold over the whole state; hence a table carefully made at any one place will serve to indicate the relative temperature of others in the same district.

We see from the foregoing table that the greatest heat of the day at Paris happens at 2 o'clock, while we know that the solar rays are most intense at 12 o'clock. We have in a previous report given an explanation of this phenomenon, namely, that the earth is constantly radiating heat into space and receiving it from the sun the whole time it is above the horizon; the temperature therefore will constantly increase while the amount of heat received is greater than that given off. The greatest amount of heat received in a minute is at 12 o'clock, and hence the increase of temperature at this time will be the greatest; but the earth after 12 o'clock still continues to receive more heat than it gives off, and hence the temperature of the air will still continue to increase, though at a less rapid rate, until about 3 o'clock in our latitude. The radiation into space from the earth and the absorption from the sun about balance each other, and the temperature will then remain stationary at its maximum point during some time, the loss and gain being equal. After this the loss is greater than the gain, and this goes on continually until the setting of the sun, when the radiation is entirely uncompensated and cooling takes place, at first with a sudden

accelerated velocity, and then gradually diminishes in intensity until daylight, when the earth has arrived at the minimum of temperature. After this, again, the earth begins to receive more heat than it loses, and the temperature of the air constantly rises again until 3 o'clock. If the earth were to radiate heat as rapidly at night as it does in the day the minimum temperature would be at about 9 o'clock in the morning; but on account of the diminished radiation with diminished temperature, the compensation takes place about the rising of the sun. When the radiation towards the sky is prevented by a transparent covering which admits the radiation from the sun, as in the case of a house lighted by windows in the roof, the maximum temperature takes place at a much later period of the day; and indeed were the radiation to the sky entirely stopped the temperature of the earth would increase indefinitely.

Temperatures below the surface.—At a certain depth below the surface of the earth there is a stratum of invariable temperature, the depth of which augments with the latitude, and in our climate is from about 100 to 115 feet. In general the temperature of this stratum appears to be a little more elevated than the mean annual temperature of the surface, and this excess appears to increase with the latitude. This stratum, it is evident, cannot be a regular surface, since it must necessarily partake in a considerable degree of the varying contour of the external surface of the earth. The first observations which were made upon this subject were in the cellars of the Observatory at Paris, at the depth of 67½ feet below the surface. They extend over a period of more than fifty years, and show an invariable temperature of 53°·28 F. The thermometer used in these observations was a most delicate one, constructed by Lavoisier, and it in no instance showed a variation of one-tenth of a degree Fahrenheit above or below 53°·28; and even these variations, small as they are have been traced to accidental causes.

Below the surface of the ground, and at a depth of from 65 to 80 feet, but few observations have been made, and these have been principally applicable to the middle latitudes of

the northern hemisphere. From all the observations Pouillet gives the following deductions:

1. The *diurnal* variations are not perceptible at depths greater than about 40 inches.

2. The mean *annual* temperature of the different strata differs little from the mean annual temperature of the air.

3. The differences between the maxima and minima of the different strata decrease in a geometrical progression, while the depths increase in an arithmetical progression.

4. From all the observations it appears that at a depth of from 26 to 29 feet, the annual variation is only 1°·8 F; at from 49 to 52 feet, it is but 0°·18 F.; and at a depth of from 65 to 81 feet, it becomes only 0°·02 F.

5. At the depth of about 26 feet, or where the variation is 2° F., the seasons are precisely reversed; that is, the maximum temperature occurs about the 1st of January, and the minimum about the end of June.

Effect of heat on plants.—We have stated that all the transformations of matter going on around us, the power exhibited in the growth of the plants, in the functions and motions of animals as well as in the winds,—are referable to impulses received from the sun; but the mere continuance of the heat of a body at a certain temperature does not produce a continuous change in it; for example, a piece of metal, when kept at the same temperature, may remain unchanged for years, provided the intensity of the heat is not sufficient to melt it. In order therefore that heat may do work, or effect a permanent change in matter, it is necessary that it be applied by means of some mechanical arrangement analogous to a machine. In most cases, an intermediate agent (such as steam or heated air) is employed in connection with the machinery, and we have a striking natural arrangement of this kind in the organization of the plant. If the stem of a plant were solid, and did not consist of minute cells filled with evaporable liquid, the heat of the atmosphere, so long as it were constant, could produce no change. To understand this, let us suppose a tube of glass with a minute bore (for instance the tube of a broken thermometer) to have

its lower end placed in water, the liquid will rise perhaps to an inch above the general level of the liquid in the vessel, and here it will remain. The cause of this ascent is the attraction of the glass for the liquid and the liquid for itself, and is familiarly known under the name of capillarity. A perpetual flow of water can never be produced by this action since if we cut off the tube before-mentioned, leaving but three-fourths of an inch above the water, the attraction of the glass will draw the liquid up to the very top, but will not permit it to run over, because the same attraction which suspends it will prevent it from overflowing. The atom of water at the top of the tube will be attracted as much downward by the glass as the next one below will be attracted upwards; hence an equilibrium will ensue.

If however we apply heat to the upper surface, which will evaporate the water, a new portion will be drawn up to restore the equilibrium; and if this process be continued, a constant current will be maintained, and a definite amount of mechanical work will be performed. If the liquid contain different substances in solution, these will be retained, it may be in a solid form, and in this way a solid substance may be brought up and deposited at the end of the tube. If across the lower end of the tube a porous membrane be stretched, and if the liquids above this, and that in the vessel below, be of a different quality, which would necessarily result on account of the evaporation mentioned, then the ascensional power would be very much increased by the process called endosmose. Without considering at present this action very minutely, we may apply the principles we have here given to the means by which heat becomes a motive power in building up a plant. The stem of a tree is an arrangement analogous to an assemblage of minute tubes, such as we have described, terminating in leaves above, from the surface of which constant evaporation is going on, and a current of liquid ascending called crude sap, which consists of water containing in solution the various substances imbibed by the roots, and elaborated by the leaves. The tubes are not continuous, but are elongated cells analogous to a glass tube, the ends of which are closed with porous membrane.

We can scarcely doubt that by this arrangement the motive power which gives rise to the circulation of the sap is the heat derived from the atmosphere and the direct rays of the sun. But a small part however of the material of which the plant is mainly built up, (namely carbon) is elevated from the roots. This is furnished, as we have before stated, by the de-composition of the carbonic acid absorbed from the atmosphere into the pores of the leaves, and there resolved by the chemical ray of the sun. It is at this place that the liquid brought up by evaporation is elaborated into true sap, under the principle of vitality, which being carried downward through the cells by endosmose, serves by secretion to build up new cells, and thus to increase every part of the plant. The rapidity of evaporation will depend, the amount of heat being the same, upon the quantity of vapor already in the atmosphere; and hence with the same degree of temperature the amount of work performed would appear to be greater in a dry than in a moist atmosphere; but since the carbonic acid which is decomposed is probably absorbed by the water in the leaf, too rapid an evaporation will retard rather than increase the useful effect.

But little is known of the minutiæ of this process, or how far the results may be influenced by other causes than those actually observed. We are assured however by observation, that beyond a certain degree of heat, a given plant cannot have a healthy condition, and also below a certain temperature, which is still above freezing, the sap of plants ceases to have an active if any circulation.

Heat necessary for the growth of plants.—The hypothesis was early advanced that for each plant a certain amount of heat is requisite in order to its developement from one stage of growth to another; for example, in the case of *wheat*, from the time it begins to sprout until it arrives at its full maturity, a definite quantity of heat is required, other conditions being the same, though the time in which it may be furnished may be different in different instances. Different methods however have been proposed for estimating this heat. Reaumur, who first advanced the hypothesis of the definite amount

of heat, as well as late writers on the subject, has proposed to calculate it by multiplying the number of days in which the plant is passing through its growth by the mean temperature of each day; while M. Quetelet, of Brussels, who has made more experiments on this subject than any other person, thinks that the heat ought to be measured, not by the simple product of the sum of the temperatures of the several days but by the sum of the squares of the temperatures of these days. He deduces this rule from the consideration that if heat be due to vibration, the impulses from it ought to do work in proportion to the square of the intensity, and not simply in proportion to the intensity. For example, a cannon ball moving with twice the velocity will penetrate a wall four times as far,—moving with three times the velocity, nine times as far,—and so on, in proportion to the square of the velocity. In accordance with this, let S represent the amount of heat required to produce the full development of the plant, and t and t' be the mean temperatures of the several days; then will $S=(t)^2+(t')^2+(t'')^2$, &c. It follows as a consequence of the law of the square of temperatures that alternation of temperatures within certain limits may produce greater effect than a uniform temperature. For example, if on three consecutive days the temperatures were 70°, 60°, and 80° F., and on three other days, 70°, 70°, 70°, though the average heat is the same, the effect of the former will be slightly greater than that of the latter; since the sum of the squares of the first is 14,900 while that of the latter is 14,700.

From *a priori* considerations there can be no doubt that to produce a given amount of organization a definite amount of power must be expended; but we are unable to say in the present state of science how much of the power which may disappear is lost in producing other than useful effects. Also, in the foregoing investigation it might reasonably be supposed that the mean heat of the day, in part, should be derived from the heat of the sun, and not alone from that of the air. The upper surface of a plant will be heated by the direct rays of the sun, while the lower will be exposed in the shade to the heat of the air. It has therefore been proposed

to employ the temperature obtained from the mean of the observed thermometer in the sun and in the shade during the day. To render this principle of use in practice, a series of observations in different seasons of the year, on the temperatures of thermometers in the sun and in the shade would be necessary. Besides this, since vegetation is comparatively but little advanced at night, the length of the day should be taken into account, which in the neighborhood of the equator is 12 hours, and in the vicinity of the polar circle, nearly 24 hours. Another correction is necessary in order to obtain strictly comparative results, namely, that which is due to the fact that different plants begin to show signs of vitality in the spring at different temperatures.

Allowing the truth of the proposition of the definite amount of heat required for the full development of each plant, we have a ready explanation of the fact that some grain will come to maturity in climates of very different temperatures, the less intensity of heat being compensated for by the longer duration of the day. Though each species of plant may require a definite amount of heat for its perfect maturity, yet this is by no means the measure of the power expended in the organization, though it may bear a definite ratio to it. The chemical ray of the sun decomposes carbonic acid, and thus furnishes the greater part of the material of which the plant is composed, and in the process of germination and assimilation, probably furnishes a portion of the power necessary to carry on these processes.

The following table is selected from the memoirs of M. Quetelet, of Belgium, and contains the times of leafing, blossoming, and fructification of plants found in this country as well as in Europe. The selection has been made at my request by Dr. L. D. Gale, of Washington, and it is hoped that the times will be compared with those pertaining to the same periods of the developments of the same plants in different parts of this country.

The observations from which the original table was constructed were made in the garden of the Royal Observatory, at Brussels, and according to the author, they may be ap-

plied not only to Belgium but also to the whole of Europe, due regard being had to the differences of latitude and elevation between Brussels and other places. The correction for each degree of latitude is four days for each degree, to be added or subtracted accordingly as the place is to the north or south of Brussels. The correction for elevation is a retardation also of four days for every 330 feet above Brussels, which is itself about 195 feet above the level of the sea. It must be understood that these corrections are only approximate, for we are obliged to abstract the consideration of the nature of the soil, the exposure of the plant, and the more or less continental locality, that is the greater or less distance from the sea.

Plants that grow in Europe and in the United States, whether indigenous or introduced—experiment continued ten years; by M. QUETELET, *of Brussels.*

NAMES OF PLANTS. (*Time of leafing.*)*	Mean time.	Earliest.	Latest.
Acer pseudo-platanus, a maple	April 20	April 7	April 28
Æsculus hippocastanum, horse chestnut	April 6	March 27	April 27
Amygdalus Persica, peach	March 28	March 4	April 19
Berberis vulgaris, barberry	March 22	Feb. 26	April 14
Betula alba, white birch	April 9	March 27	April 20
Bignonia catalpa, catalpa tree	May 1	April 17	May 19
Cratægus oxyacantha, English hawthorn	March 23	Feb. 25	April 16
Clematis viticella, Italian clematis	March 25	Feb. 23	April 20
Daphne mezereum	March 13	Feb. 23	April 4
Fraxinus nigra, black ash	April 26	April 15	May 5
Gleditschia ferox, honey-locust tree	May 9	April 30	May 26
Juglans nigra, black walnut	April 28	April 19	May 10
Lonicera Tartarica, Tartarian honeysuckle	March 6	Jan. 30	April 5
Magnolia grandiflora, gr. flower magnolia	April 19	April 4	April 29
Morus alba, white mulberry	May 2	April 21	May 15
Philadelphus coronarus, mock orange	March 18	Feb. 23	April 13
Populus alba, white poplar	April 12	April 1	May 1
Populus balsamifera, balm of Gilead	April 5	March 14	April 22
Prunus cerasus, cherry laurel	April 6	March 27	April 21
Prunus domestica, common plum	April 2	March 6	April 28
Prunus spinosa, sloe, black thorn	April 1	March 1	April 23
Pyrus communis, common pear	March 30	March 10	April 22
Pyrus malus, apple	March 30	March 12	April 20
Rhus typhina, staghorn, sumach	April 19	April 1	May 7
Ribes grossularia, gooseberry	March 8	Feb. 18	April 3
Ribes rubrum, red currant	March 17	Feb. 25	April 8
Ribes nigrum, black currant	March 17	Feb. 24	April 8
Robinia pseudo-acacia, white locust	April 23	April 9	May 10
Sorbus aucuparia, mountain ash	April 7	March 18	April 21
Tilia Europæa, European linden tree	April 7	March 18	April 22

* Latitude of Brussels.

Table of Plants—Continued.

NAMES OF PLANTS. (*Time of flowering.*)	Mean time.	Earliest.	Latest.
Acer pseudo-platanus, a maple	April 28	April 19	May 10
Achillæa millefolium, yarrow	July 13	July 5	July 30
Aconitum napellus, monkshood	June 1	May 15	June 12
Æsculus hippocastanum, horse chestnut	May 3	April 23	May 16
Amygdalus Persica, peach	March 20	Feb. 27	April 8
Amorpha fruticosa, common false indigo	June 12	May 28	June 24
Anthemis cotula, mayweed	June 5	May 6	June 19
Berberis vulgaris, barberry	May 4	April 18	May 20
Betula alba, white birch	April 8	March 22	April 22
Cratægus oxyacantha, English hawthorn	May 4	April 16	May 23
Clematis viticella, Italian clematis	June 29	June 2	July 14
Daphne mezereum	March 15	March 3	April 2
Lonicera Tartarica, Tartarian honeysuckle	May 9	April 23	May 23
Magnolia grandiflora, gr. flower magnolia	April 16	March 8	April 25
Morus alba, white mulberry	May 22	May 15	June 3
Philadelphus coronarius, mock orange	May 23	May 11	June 4
Populus alba, white poplar	March 23	Feb. 28	April 20
Populus balsamifera, balm of Gilead	March 23	Feb. 28	April 20
Prunus cerasus, cherry laurel	April 16	April 2	May 4
Prunus domestica, common plum	April 16	March 27	May 3
Prunus spinosa, sloe, black thorn	April 7	March 2	April 30
Pyrus communis, pear tree	April 13	March 9	May 2
Pyrus malus, apple	April 25	April 12	May 8
Rhus typhina, sumach	July 13	July 5	July 25
Ribes grossularia, gooseberry	April 3	March 12	April 22
Ribes rubrum, red currant	April 2	March 18	April 22
Ribes nigrum, black currant	April 14	March 28	April 30
Robinia pseudo-acacia, white locust	May 30	May 17	June 12
Sorbus aucuparia, mountain ash	May 2	April 16	May 15
Tilia Europæa, linden tree	June 9	May 15	June 17

NAMES OF PLANTS. (*Time of fruit.*)	Mean time.	Earliest.	Latest.
Acer pseudo-platanus, a maple	Oct. 30	Oct. 25	Nov. 3
Amygdalus Persica, peach	Aug. 22	Aug. 5	Sept. 11
Prunus cerasus, cherry laurel	June 11	May 30	June 24
Pyrus communis, common pear	Aug. 26	July 28	Sept. 14
Ribes grossularia, gooseberry	June 25	June 16	July 8
Ribes rubrum, red currant	June 15	June 6	June 29
Ribes nigrum, black currant	June 15	June 8	June 27

Heat on different surfaces.—The amount of heat which falls upon a given surface depends upon the inclination to the different points of the horizon. A field, for instance, in our latitude sloping towards the south, receives a greater, and one towards the north a less amount of heat; moreover, the former obtains more than an equal extent of ground parallel

to the horizon, and the latter, as in the other case, much less. A field also which slopes in an easterly direction receives less heat than another inclined towards the west, inasmuch as more reaches the latter, since the maximum heat of the day takes place after the sun has passed the meridian; as it is, each of these enclosures gets a less amount than one of equal extent parallel to the horizon.

Estimate of temperature by rings in trees.—It frequently happens that permanent records are found of the past condition of our globe in the impressions retained in the rocky strata, and that the yearly occurrences of certain phenomena such as the annual deposit from the overflowing of rivers. Such records may be rendered available in determining the time of actions which may have long since ceased, or which continue to the present day. It is well known that the trees of our latitude increase in size by the deposition of an additional layer annually between the wood and the bark, and that a transverse section of such a tree presents a series of concentric though irregular rings, the number of which indicates the age of the tree. The relative thickness of these rings depends on the more or less flourishing state of the plant in the year in which they were formed, and therefore indicates the relative state of heat and moisture during the same period. Furthermore each ring in some trees may be observed to be subdivided into others during the same year, indicating that the vegetation was advanced or checked at intervals during the season. Furthermore it has been found by observation that even the motion imparted to a tree by the wind has an influence on its growth, giving to its trunk an oval form, the longer direction of which will be that of the prevailing wind. A thin slice therefore cut from a large tree at right angles to its axis, carefully polished and varnished, forms a natural record of the weather well calculated to call forth admiration and to impart instruction. It is scarcely necessary to remark that the year should be carefully identified, corresponding to a given circle, in order that the whole might be properly numbered.

Mr. Babbage has proposed an ingenious application of this

principle for carrying back the series of records by means of trees which are found in the deep bogs of different parts of Great Britain. By searching for corresponding thick or thin rings in the outer circumference of one tree and in the inner of another, a number of trees may be arranged in a series, and thus the record extended back into the geological periods. Whatever may be the practical value of this plan, it is certainly ingenious and worthy of attention. Since the trees found in bogs are, we may suppose, the regular and consecutive productions of the primitive forests, they would probably represent the successive vegetation of a series of centuries.

The remains of plants found in the rocky strata indicate that the same diversity of weather and the same changes of seasons existed in the past geological ages as at the present time. By carefully studying the rain marks on sandstone, the direction of the wind during storms in the ancient periods may be determined; and this will probably be found the same as in thunder showers of the present day. The remains of plants and animals of a tropical character found abundantly in the northern regions assure us that the temperature of the surface of the whole globe has undergone remarkable changes.

Effect of different surfaces.—The rays of heat from the sun which strike the earth are partly reflected into space and partly absorbed by the surface in producing an elevation of temperature. The absorbent and reflective powers are complementary to each other, and vary greatly in different substances, and as we have seen according to their color and texture. Lampblack possesses this power of absorption in the greatest degree; and if we represent this by 100, that of common glass will be 90, and that of polished metallic surfaces about 6. Consequently, the latter have a high reflective power, while that of lampblack and other dark substances is very small. This is a matter of interest to the agriculturist, since the amount of heat which may be received by a given surface will depend very much upon its color; and indeed in some cases, charcoal or other dark sub-

stance has been strewed over the ground to increase its absorbtive power.

The following table by M. Schubler is copied from Becquerel, and gives the greatest elevation of temperature obtained by different soils exposed to the direct rays of the sun, while the surrounding air was at about 78°.

Maximum of temperatures of various earths exposed to the sun, by SCHUBLER.

KIND OF EARTH.	Maximum temperature of the superior layer, the mean temperature of the ambient air being 77° F.	
	Moist earth.	Dry earth.
	°	°
Silicious sand, yellowish gray	99·05	112·55
Calcareous sand, whitish gray	99·10	112·10
Argillaceous earth, yellowish gray	99·28	112·32
Calcareous earth, white	96·13	109·40
Mould, blackish gray	103·55	117·27
Garden earth, blackish gray	99·50	113·45

The differences of temperature exhibited by the two columns are due to the heat expended in the evaporation of a portion of the water in the moist earth, while the differences between the substances are to be ascribed principally to the colors, though the texture may have some effect.

Absorptive power is connected with that of emission; and those bodies which possess the greatest absorptive power for heat of a low intensity, also possess the greatest emissive power for heat of the same kind. But the preceding remarks have reference to the rays from the sun and not to those of dark heat, and here I must stop to recall the fact which is frequently neglected, even by scientific men, namely, that color has no effect upon the absorption or emission of rays of low intensity. For example, if we pass our hands over a sign-board on which dark letters upon a white ground are exposed to the sun we can readily perceive with our eyes shut the difference of temperature; but this would not be the case were the board exposed in the dark to the heat of

a stove of a temperature below redness. Furthermore if the same board were exposed to the clear sky and suffered to cool by its own radiation no difference of temperature would be observed in the different parts of its surface, except a very slight one, which might be due to the difference of the radiating power possessed by the substances of which the black and white paints are composed. On this subject Prof. Bache, the Superintendent of the Coast Survey, has made a series of very interesting experiments. He found that canisters of tinned iron painted externally of different colors and filled with heated water, required the same time to cool through a given number of degrees. The facts in regard to this point may be generalized by saying that color has no influence whatever upon the emissive power of different bodies, but that its influence is confined to the reception of rays of high intensity, or those which approximate in quality to the luminiferous emanations. Hence a black or a white dress is equally cool in the night, though in the sunshine the darker one would absorb the greater amount of heat.

Besides the color, the humidity of the soil has great influence upon the temperature it acquires, a portion of the heat being expended in evaporating the water. We have seen the statement somewhere that the average temperature of whole districts in Great Britain has been elevated one degree by the system of drainage adopted in that country.

In addition to the preceding causes, there are two others which affect the temperature of the soil, namely, conduction and capacity for heat. In a porous, badly conducting substance the heat which may escape from the surface is not readily supplied from the interior, and hence such bodies are long in cooling. Again, different bodies contain very different amounts of heat at the same temperature, and hence one body may take a much longer time to cool down to the same temperature through the same number of degrees than another. That two different bodies of the same weight at the same temperature possess different amounts of heat may be shown by first heating say a pound of each in boiling

water, and afterwards plunging them separately into equal amounts of cold water of say 32° F. It will be found that the heat which they severally impart to the water in the two cases will be very different.

The following table, also from Becquerel, gives the relative retention of heat by different soils, (that of calcareous sand being one hundred,) and also the time of cooling of cubes of 3·2256 inches (550 cubic centimeters) of the different earths.

Table of retention of heat, by BECQUEREL.

KIND OF EARTH.	Capacity for heat, that of calcareous sand being 100.	Time required by 33 cubic ins. of earth to cool from 144°·5 to 70°·2, the temperature of the surrounding air being 61°·2.
		hours.
Calcareous sand	100·0	3·30
Silicious sand	95·6	3·27
Argillaceous earth	68·4	2·24
Calcareous earth	61·8	2·10
Mould	49·0	1·48

Effect of Cold.

While the periodic temperature of a given place depends upon the position of the sun in its course, the abnormal hot and cold periods, or terms, as they have sometimes been called, are due principally to winds from certain directions. The cold terms in this country generally begin in the northwest and advance southerly and easterly, and are accompanied with winds from the north and northwest. We do not however intend in this place to discuss these abnormal variations of temperature, but to consider the effect of cold on different bodies, including plants and animals. We shall first consider its effects on a surface of water.

Effect of cold on water.—When the surface of water is exposed to a low temperature, the upper stratum is cooled, becomes specifically heavier and sinks. A lower portion then comes to the surface which in its turn is cooled, be-

comes heavier, and again gives place to another stratum, to pass through the same process. This continues till the column of water originally included between the surface and the bottom is reduced to a temperature of about 39° F., at which point the fluid ceases to shrink, or in other words to become heavier, but on the contrary, expands with every diminution of heat until it becomes entirely solidified. After it has assumed a solid condition, it follows the law observed by other solids and shrinks with every subsequent fall of temperature. After the water of a given reservoir has arrived at a temperature of 39°, since it does not increase in weight, it continues to float on the surface, and is rapidly cooled down to 32°, or the point of congelation. Before however it can be converted into a solid at this temperature, it is necessary to abstract from it a large amount of latent heat.

To render this plain, let us suppose a lump of ice, taken at zero, and with the bulb of the thermometer in it, placed under such conditions that it shall receive from surrounding bodies one degree of heat in one minute of time. We shall find in thirty-two minutes the thermometer will come up to the freezing point; but here we shall observe that the mercury ceases to rise, although the supply of heat remains the same, and it will continue stationary during one hundred and forty minutes, or until all the ice is melted, after which it will again begin to rise, and continue its upward march until the water begins to boil, when a second stationary point will be reached. The heat which continued to flow into the ice during the stationary period, was necessary to convert it from a solid to a liquid state, and inasmuch as it does not affect the thermometer, it has been called latent or concealed heat. Water at 32° therefore contains 140° of heat more than ice at the same temperature.

In the freezing of water, a reverse process takes place, and 140° of heat have to be abstracted before the liquid is converted into a solid. Freezing is therefore comparatively a slow process, independently of the previous cooling down of the whole mass in the reservoir to 39°, and the upper film to 32°. For example, if on the exposure of a stratum of water

at a temperature of 20° above freezing, to the air below 32°, it requires twenty minutes to reduce it to the point of congelation, one hundred and forty minutes will be required to solidify it—or seven times as long.

In melting the ice, the same amount of heat has to be absorbed, so that a large extent of deep water becomes a regulator of temperature, preserving the air immediately over it at near 32°, though the atmosphere in the vicinity during the winter may be far below zero; conversely in the spring, though the temperature of the same latitude may be 60° or even 80°, that of the air immediately over the water will be near 32°. It is evident from these facts that the deeper the reservoir, the longer will be the continuance of low temperature required to freeze the surface, and the longer the time necessary for melting it again. These principles are illustrated in our great lakes. The greatest known depth of Lake Superior is 792 feet, and soundings of 300, 400, and even 600 feet are not uncommon. In the coldest weather, the water over these deeper places is above 32°, and does not freeze, while over the shallow parts a coating of ice is formed, which gradually cooled by the slow diffusion of the water underneath, retains its solidity until the last of June. Indeed, ice is sometimes found at the surface in the middle of July. At this period of the year, or a little later, the smaller ponds of water in the vicinity have a temperature of 72° to 74°. Lake Erie, being much shallower, sometimes freezes entirely across, and becomes in summer heated throughout its extent to nearly the temperature of the supernatant air. At the beginning of September, 1857, the temperature of Lake Huron was 56°, while that of the water from Lake Erie, which passed over the falls of Niagara, was 72°, precisely that of the air.

All bodies, as we have previously said, in passing from a liquid to a solid state, tend to assume a regular geometrical arrangement called crystals. This is particularly observable when the process has been slow, and undisturbed by agitations and tremors. The form peculiar to each substance is exhibited when a portion only of liquid has assumed the

solid state, as in the case of the shooting of spicules across the surface of water in a metallic basin exposed to the cold. It will be found on inspection that the filaments of ice arrange themselves at definite angles of either 60° or 120°, and that the triangular openings are bounded by sides making the same angles with each other. In reference to crystallization, there is an important law to be borne in mind, namely, that the axis of the crystal always tends to be at right angles to the surface of the cooling mass. For example, if a quantity of melted zinc be poured into a cylindrical hole in cold sand, and the bar thus formed be broken across, the crystals will be found to be arranged in the form of radii, with their bases in the circumference; and in some cases there will be found a cylindrical hole along the axis, from which the metal has been drawn away by the shrinking at the time of cooling and crystallization. A precisely analogous arrangement takes place in the freezing of water, which may be observed by placing a quantity of this liquid in a globular glass vessel, and submitting it to a temperature of some 10° below freezing. We shall find then that the crystallization will begin at all sides of the globe, and proceed gradually towards the centre, expelling before it all the air, and most of the foreign substances which may be contained in the water. If the cold be continued, the freezing will proceed toward the middle, until finally the process would end by collecting at this point a quantity of air surprising in amount. Before this takes place however, the glass vessel will be broken by the expansion of the ice. The crystallization at the upper surface of the water will be somewhat irregular at first; the spicules of ice around the margin will tend to shoot out at right angles to the surface of the glass; but after a pellicle has formed over the top of the fluid, this will serve as a point of attachment, and the crystallization will go on, as in the other case, at right angles to the surface; the air bubbles will be driven down before it, and if the freezing be very gradual the air will be entirely expelled, and the ice assume a perfectly transparent and homogeneous structure. If the freezing be more rapid, the air

which has been expelled from the higher stratum will be caught by that next below, and in this way we shall have a series of air-bubbles extending downwards to the surface of the unfrozen water.

Accustomed as we are to see bubbles of air rise in the water, it would appear at first sight that the bubbles seen in ice come up from the water below; but from actual observation in the manner we have described, it is clearly proved that the bubbles are composed of air which had been absorbed at the surface of the water and expelled downward from stratum to stratum in the process of freezing.

The ice then over a lake or pond consists of crystallized water, of which the axis of crystallization is at right angles to the surface and the principal cleavage in the same direction. It results from this that in the thawing of the ice in spring it tends to resolve itself into innumerable prismatic crystals at right angles to the surface, and is liable to be disintegrated by a strong wind in a single night, thus producing the phenomena of a sudden disappearance of ice over a large surface, a fact which has been erroneously attributed to its sinking, an evident impossibility, since the minutest portion of crystallized water is specifically lighter than the same substance in a liquid form. General Totten several years ago arrived at the same conclusion as to the sudden disappearance of ice which I have demonstrated in the experiments before mentioned.

Ice before it tends to give way becomes pervious to water, which is readily transmitted through the interstices of the crystals; hence those who are accustomed to travel on frozen lakes or rivers are aware of the fact that so long as the water of the melted snow does not pass through the surface of the ice underneath, it is safe and in a sound condition, though we must be careful not to confound this water with that forced up by hydrostatic pressure from below, on account of the bending downwards of the whole field.

A simple method has been proposed for determining the relative severity of different winters, by observing the thickness of ice. For this purpose a shallow vessel of water is

exposed to the air and the thickness of the ice produced measured each day. From what has been said it is evident —first, that the vessel should be made of wood or some other non-conducting substance, in order that the freezing may not take place at the sides; and second, that the water should be always of the same depth; for if there be two vessels of the same diameter, one containing more water than the other, the thickness of ice formed in the two will be different, unless the fluid in both is at the temperature of *thirty-two* degrees at the commencement of the exposure. If we would ascertain more accurately the measure of effect, the ice must be broken and its thickness measured or the amount weighed very carefully every day, for if we suffer it to accumulate we shall have a less result, since the first coat tends to screen the water, so that with the same temperature the process goes on more slowly. This method is very simple, and when properly employed furnishes reliable data for determining the relative intensity of different winters. By simply measuring the thickness on a lake or pond from year to year we may approximately arrive at a similar result. But as we have said the upper stratum screens the lower ones, and a knowledge of this fact has been taken advantage of in some parts of New England to increase the quantity of the ice for economical purposes. To this end water is suffered to flow over a surface of ice already frozen, and thus by frequently repeating the operation a much greater aggregate thickness of ice is produced. Ice made in this way is more porous however and contains more air than that formed by ordinary freezing, since all the air evolved from the strata after the first must be retained by the next below.

The more solid the ice, the longer it will resist thawing; first, because it contains more water under a given external surface, and second, because a portion of radiant heat is always absorbed at any surface, whether it be external or internal; for example, if we expose a piece of ice containing a bubble of air to a source of radiant heat, we shall find that the bubble will gradually enlarge, thus proving an internal melting to be going on. In the preservation of ice for

domestic purposes it is therefore important that it should be gathered in masses as thick and large as possible. The lower side of the ice, as a general rule, contains more impurities than the upper, since the process of crystallization tends to expel all the foreign ingredients downwards; and hence a storehouse filled with thin ice will contain more impurities, and, on account of the multitude of bubbles and amount of surface exposed, will melt much sooner than if well packed with thicker blocks. The temperature of ice moreover may be reduced considerably by exposure for some time to the weather, when below the freezing point, and thus the value of its cooling effect be enhanced. This diminution of temperature however is continued only by the slow conducting power of the ice, and though it may retard considerably the melting of the mass, we think the effect is scarcely perceptible in ice transmitted to warmer climates. We have never found a thermometer, inserted in a hole in the centre of blocks of Boston ice, in the city of Washington, to sink below 32°. In filling the ice-house however and in compacting the mass, advantage should be taken of the coldest weather.

In the preservation of ice the smaller the amount of surface exposed between the several parts, and the greater the amount accumulated in a given place, the longer it will resist melting; for the tendency to become liquid will be in proportion to the surface exposed, since the heat which produces this effect must pass through the surface; for example, in a cubic block of ice, measuring one foot on each edge, there are six surfaces exposed, each one foot square. Now if we cut this same block into two parts, by a plane parallel to one of the sides, we shall present two additional faces each a square foot in extent, and the aggregate amount of surface exposed will be increased in the ratio of six to eight. For a similar reason, if we have two ice-houses of like form, the one ten and the other twenty feet in diameter, the capacity will be in the ratio of one to eight, while their surfaces will be as one to four; hence the tendency to resist melting will be in direct proportion to the diameters of reservoirs of similar forms.

Of all geometrical solids, a sphere is that which contains

the greatest amount of space in a given surface. All other conditions being equal, we should choose this form of excavation for preserving ice; but on account of the difficulty of lining a pit of this shape, we may select the next most economical form, which is the cylindrical. It is scarcely necessary to mention in this connection the fact that, in order to succeed in preserving ice, it should be well protected from the surrounding earth and air by strata of non-conducting materials, such as straw, powdered charcoal, or saw-dust, the greater the thickness of which, the better the purpose in view will be answered. The house should also (as an additional precaution) be shaded above by trees, and have the cover painted white, to reflect back the more intense rays which may reach it indirectly. Morever the ice should not be suffered to rest upon the bare ground below, but on double floors, between which a non-conducting substance is placed, communicating by holes with a deep pit or drain through which the water from the melted ice may percolate.

We have stated that water at 39°·1 begins to expand, and that this expansion increases until solidification takes place. The force exerted by this expansion is immensely great, being sufficient to burst a cannon or to cause water to pass in the form of a fine frost through the pores of solid metal. When however this expansion is opposed by a sufficient external pressure the water is not converted into a solid at thirty-two degrees, but assumes this condition at a lower temperature; a piece of ice therefore at thirty-two degrees subjected to a great pressure ought to be converted into a liquid; and this may serve to explain a fact frequently noticed, that pieces of ice thrown upon each other adhere at the points of contact—the percussion changing these surfaces from a solid to a liquid, which immediately afterwards solidifies again. But this cause is scarcely sufficient to explain the very remarkable fact that if two lumps of ice be placed so as to present two flat surfaces and these be pressed together they will unite as one mass; and this will take place even in hot water while the external surface is rapidly melting. The pressure necessary to bring them into contact would no

doubt tend to produce the effect we have already mentioned, though it is not improbable that the melting of the ice, as in the case of the evaporation of water, tends to reduce the temperature slightly below 32°. Prof. Tyndall, of the Royal Institution, has recently made an interesting series of experiments on the plasticity of ice. He finds that it may be bent and moulded into a variety of forms by subjecting it to pressure, particularly when near the melting point, and has very ingeniously applied this property to the explanation of the stratified appearance of some of the glaciers. If pressure is applied to any plastic substance in which are disseminated globules of air or irregular patches of other material, the mass will assume a lamellar structure at right angles to the direction of the compressing force; and in this way the laminated appearance which is exhibited after the confluence of two separate streams of ice which exert a great pressure upon each other is explained.

It is well known that when alcohol and water are mixed together the attraction of the two bodies is so great that a diminution of bulk and a consequent rise of temperature ensue. The same affinity exists between ice and alcohol; but when these are mixed, strange to say, a considerable *diminution* of temperature is the result; and those who habitually or otherwise mingle these two ingredients as a beverage, are sometimes surprised to find the fragments of ice frozen in a solid mass to the spoon by which the mixture is stirred. When two liquids having an attraction for each other are mingled together and a diminution of bulk ensues, heat must be evolved on account of the power generated by the approach of the atoms. For an analogous reason, when the attraction between the atoms of two bodies is diminished a quantity of heat must disappear; hence when a solid is dissolved in a liquid for which the attraction is not very intense, a quantity of heat disappears or cold is the result. In the case of the alcohol and ice, the cold produced by the liquefaction of the solid greatly exceeds the heat which might be produced by the union of the water and the alcohol. When the affinity however is very great, as between nitric

acid and copper, then the heat of the chemical combination of the two substances far exceeds the cold due to the liquefaction of the solid, and a high temperature in the mixture is the result.

On the same general principle is explained the melting of ice by sprinkling the surface of it with salt,—a process sometimes resorted to for clearing the sidewalks after an intense cold has succeeded rain. The union of salt and ice produces a liquid the freezing point of which is many degrees below that of water; and hence on their contact in a solid state, liquefaction necessarily ensues; and this in accordance with the general law must be attended with a great reduction of temperature in the surrounding bodies; on which fact depends the application of salt and snow to artificial freezing, as in the manufacturing of ice-cream. In places where ice is scarce the same principle may be applied to produce a much greater reduction of temperature from a smaller quantity of this substance. Three parts of ice and one of salt mixed together in a thin vessel will reduce the temperature of a large quantity of water; and since the same salt may again be obtained in a solid form by exposing the solution to the sun we think such a freezer might in some cases be economically employed.

The artificial production of ice in hot countries on a scale sufficient for domestic use, has of late it is said been successfully accomplished. An attempt of this kind was made a few years ago at New Orleans, by means of the rapid evaporation of water, but the cold produced in this way being small the process was not sufficiently economical to enable the manufactured article to compete in price, in that city, with the abundant supply of ice imported from New England.

Another process, which is said to be more effectual, is that of a Mr. Harrison, of England, and consists in the evaporation, liquefaction, and re-evaporation of ether. If the bulb of a thermometer covered with cotton and wet with ether be exposed to the atmosphere, the cold produced by evaporation will cause the mercury to descend many degrees below the freezing point; and if the evaporation be made to take

place under the receiver of an air pump, a much greater reduction of temperature will be produced.

Although we have not seen any account of the apparatus for reducing to practice the plan above referred to, we can readily imagine an arrangement which would produce the result. For this purpose, it would be sufficient to put the water to be frozen in thin tightly closed vessels, and place them in a large receiver containing ether, the latter being connected with an air pump, of which the upward stroke should exhaust the atmosphere, and the downward stroke re-condense the vapor in a separate vessel, to be again let into the freezing receiver, and so on.

The establishment of the ice trade, for which the present age is chiefly indebted to an enterprising citizen of Boston, must have a beneficial effect upon the sanitary condition of the world. The white man is especially adapted by his physical organization to the temperate regions, and succumbs to the intensity of the prolonged heat of the tropics unless through the agency of science he is enabled to ameliorate the effects of the ardent rays of a nearly vertical sun. An abundant supply of ice not only adds to the comfort of the European in India, but is indispensable to the continuance of his health. The use of this article will probably be very much extended, and by a suitable system of ventilation applied to the cooling of the air of apartments in a manner analogous to that of heating them during the rigor of winter at the North.

The expansion of a quantity of water passing into a solid state will be in the direction of least resistance, and hence we find a bulging up in the centre of the ice in a pitcher; but if the freezing be continued the thickening of the ice in this direction will produce a re-action in other directions, which causes the rupture of the vessel. This expansion, as we have stated before, only takes place while the water is in the act of solidifying; and it is not the stratum of ice first formed which causes the bulging up in this case, but the expansion of the water beneath. This is fully explained by the plastic character of ice before mentioned. If the bulg-

ing up however be too great, cracks are produced at the most elevated parts.

After a quantity of water has been solidified it ceases to expand; and with a still further diminution of temperature shrinks, in accordance with the law to which all solid bodies are subjected. Indeed it is now known that most liquid substances which pass into the solid state enlarge their volume at the moment of transition, and that the phenomenon exhibited by ice is only a conspicuous illustration of a general rule. Ice once formed is found to shrink more rapidly with a diminution of temperature than any other substance on which experiments have yet been made.

The expansion of water and shrinking of ice serve to explain a variety of phenomena presented in the operations of nature and the processes of the arts. Those who reside near the borders of rivers or fresh-water lakes are often startled during cold winter nights by explosions apparently as loud as those of discharges of heavy ordnance. These are produced by the rupture of long lines of ice—the gradual shrinking of which has been going on during the reduction of temperature tending to bring the whole mass into a state of tension, which is relieved by the sudden giving way along the line of least strength. I am informed by Captain M. C. Meigs, who has paid particular attention to the cracking of ice on Lake Champlain, that it most frequently takes place in the narrower parts of the lake—the shrinking of portions on each side of this line of least resistance tends to separate the two masses. The water sometimes rises in the cracks thus formed, a new freezing takes place, and when the weather moderates and the field expands to its original dimensions, it becomes too large for the area it covers, and long ridges are thrown up.

A similar effect is sometimes produced on the surface of damp ground subsequently frozen. During the winter of 1856 and 1857, we received accounts of injury done to several brick houses by the separation due to the shrinking of the surface, passing through the foundation of the edifice, and extending up along the walls. We might infer from the

principles already stated that the line of separation would in preference pass through a house, as this is the direction of least resistance, for the cellar may be considered as a line of fissure between the two masses of earth, or a crack already commenced.

During a very cold night when the temperature is rapidly diminishing, and the ground covered with snow slightly encrusted on the surface by previous thawing and freezing, a continued series of minute explosions may be heard depending in frequency and loudness upon the thickness or thinness of the crust. In some cases it resembles a crackling, and at others a series of distant though not loud or sharp explosions.

There is a phenomenon connected with ice in rivers which has given rise to much discussion as to its cause. I allude to the freezing which takes place at the bottom of running streams, where in some cases the ice remains until it is separated by its buoyancy and rises to the surface. It presents a peculiar angular appearance, and is sometimes known by the name of *anchor ice.* Its formation appears to be an exception to the general rule of the freezing of water, which on account of the decreasing density usually takes place at the surface. It was at first supposed that it was due to the radiation of heat through the clear water above; but Arago has shown that this explanation cannot be the true one, since rays of low temperature cannot pass through water, and hence no such radiation can take place. A more probable explanation has been given, I think, by the same author, in referring it to the fact that still water can be reduced below the freezing point without congealing, and that it will immediately be converted into ice if a bit of solid matter be thrown into the vessel in which the experiment is made, which may serve as a nucleus for the crystallization. When water in this state is passing through a rapid channel it is mixed together and the coldest as well as the warmest part is brought into contact with the bed of the stream, the materials of which acting as a point of rest serve as a basis of crystallization.

Peculiar mechanical effects are sometimes produced by alternations of thawing and freezing,—as for example in the case of water pipes constructed of lead or other malleable metal. To render this plain let us suppose a lead pipe one foot in length to be filled with water, and after being hermetically sealed at each end exposed to a low temperature; the expansion would merely stretch the pipe, the extension not being sufficient to burst it, and no continuation of cold or increase of its intensity would produce any further effect, as this would merely cause the ice to shrink; neither would thawing and re-freezing produce any effect, since the water would merely return to its original volume, and the ice again expand to the same extent as before; but if the pipe communicated with a reservoir of water, so that when the thawing took place, the whole space, enlarged by the previous freezing, were again filled with water, a second freezing would produce another enlargement of its internal capacity, and a third thawing and freezing, under the same circumstances, would repeat the process until at length the sides of the tube would give way.

Effect of cold on plants.—Plants filled with sap and exposed to a low temperature are variously affected, according to the character of the plant, the duration of cold, and the season of the year at which it occurs. A sudden cold will tend to burst the cells. The velocity of the motion of the sap depends principally on the amount of evaporation from the leaves and stems, and this diminishes with temperature, all other things being the same; hence there is a certain degree of cold at which the sap ceases to flow, and the functions of the plant are suspended.

The different parts of the same plant are killed at different temperatures below 32°; the more succulent and tender growths suffer first, and the woody portion, or that in which the sap is better defended by non-conducting materials, last. A sudden fall of temperature, (even though it be extreme,) if of short duration, may not penetrate to the sap and produce freezing. It would also appear that the sap of different plants congeals at different temperatures, and it is highly probable

that other changes than those of a mechanical character are produced; but on this subject much research is required, and every intelligent farmer may add important materials to our stock of knowledge by carefully recording the observations he may make relative to the reduction of temperature, and its continuance, by which certain plants are destroyed.

It is shown by repeated observations that alternations of freezing and thawing are more hurtful to the tender plant than a uniform continuation of cold; whether this is produced by an action analogous to that we have described in reference to the water-pipe, or is due in part to other changes we are unable to say. When however the sap of a plant killed by frost is examined with a microscope, we find in it portions of destroyed tissue. It has also been observed that air may sink a few degrees below the freezing point without injury to the plant, provided the air at the time be very dry. It would seem from this that the freezing of the vapor and the production of the minute crystals which constitute hoar frost are in a degree essential to the effect.

As a general deduction from chemical and mechanical principles, we think no change of temperature is ever produced in plants without the concurrence of actions such as here indicated. Hence, in mid-winter, when all vegetable functions are dormant we do not believe that any heat is developed by a tree, or that its interior differs in temperature from its exterior further than it is protected from the external air. The experiments which have been made on this point, we think, have been directed by a false analogy. During the active circulation of the sap and the production of new tissue, variations of temperature belonging exclusively to the plant may be observed; but it is inconsistent with general principles that heat should be generated where no change is taking place.

Effect of cold on animals.—All animals, so long as life continues, generate heat, and have temperatures peculiar to themselves. In the higher class of air-breathing animals this temperature varies within comparatively slight limits under the influence of motion, rest, or of external circum-

stances; and a reduction of temperature by the application of external cold produces, as is well known, a sluggish condition, which finally terminates in death. The effect of external cold can be prevented by artificial covering, or it may be obviated, in the case of domestic animals, by an extra allowance of food. The sagacious farmer is aware of the fact that a well-sheltered enclosure for cattle is not only a humane but an economical provision.

Many observations have been made on the temperature peculiar to different animals, and a considerable number of observations recorded of a less scientific character in regard to the effect of the variations of temperature to which they may be subjected without permanent injury. The most astonishing fact, and one which could scarcely be believed if we were not in this country familar with it, is that many cold-blooded animals can be actually frozen, and be to all appearance dead, and yet be revivified by gradually thawing in water near the freezing point.

Fish, as we are assured on credible authority, are often brought to our northern markets from a great distance in a frozen condition, and may be restored to life by the process we have mentioned.

This is a subject, as it appears to me, of high interest in a physiological point of view, and would richly repay the application of well-devised systems of investigation. Can it be possible that the animal is frozen entirely through, and that every vital act is suspended? To what degree can a like result be produced on warm-blooded animals, and how far can the state of hibernation be prolonged without death to the individual? Will it ever be possible, in the case of any of the higher mammalia to so maintain the unstable equilibrium of constitution as to prevent decay, and at the same time to preserve in a latent state the vivifying principle? Though investigations on this point would be interesting we can scarcely hope to realize from them one of the fancies of Dr. Franklin, that of sending representatives of one age down to another to keep alive more actively the sympathies of the present with the past.

Effect of cold on the ground.—The depth to which ground is frozen in some places from year to year, is also an indication of the severity of the seasons; the effect of cold will penetrate very differently however in dry and moist soil; in the first it will depend entirely on the conducting power of the material, and in the second, it will also depend upon the amount of water to be congealed. The conducting capacity being the same, the depth to which the given degree of cold will penetrate will be much greater in dry than in wet soil, on account of the great amount of latent heat given off by the water before it is solidified. In dry conducting soil the propagation of cold downwards may continue some time after the surface of the ground has become considerably heated.

In a conducting body all parts tend to an equilibrium of temperature. If the upper end of a vertical iron bar be heated and then removed from the source of heat, it gradually becomes cooled, while the other parts increase in temperature, until gradually an equilibrium is established; conversely, if we cool the upper end of the bar, it will take heat from the next lower part; and this from the next, and so on, until the cooling reaches the extreme end, which will be cooled last. If, before the cooling has reached the lower end, we heat the upper part, the next below will be heated, and so on, proceeding downwards; thus waves, as it were, of heat and cold may be sent through the length of the bar, becoming less and less in intensity as they descend. In this way explanations have been given of the phenomenon of caverns colder in summer and warmer in winter,—the cold wave due to a lower temperature requiring six months to reach the point of observation.

The freezing of the ground in certain soils is hurtful to vegetation; the frozen stratum expanding irregularly from below heaves up the surface, and frequently loosens or breaks the roots of the plant. A covering of snow is a protection, since this substance from its flocculent nature and the air entangled in it is a bad conductor of heat. As a general rule during cold weather a thermometer in air on the snow

will exhibit a lower temperature than one under the same material at the surface of the ground. This effect however is not entirely due to the screening influence of the covering, but in part to the fact that the intense rays of the heat of the sun as well as those of the light of the same body penetrate the crystals of the snow as they do the glass covering of a hot-house, and being absorbed by the dark ground beneath elevate the temperature. For the same reason in bright days the snow next to the slate roof of a house is seen to melt, while the upper surface remains unaffected.

There is a singular phenomenon observed during the spring of the year in damp, sandy places, which has attracted much attention, namely, the ice-columns which spring from the earth during cold nights, elevating small gravel-stones on their tops, and raising as it were above its usual level the general surface of the ground. These crystals have been carefully studied by Professor John Le Conte, and appear to be due to the law we have before mentioned of the axis of crystallization being always at right angles to the surface of cooling, as well as to the attraction of the water for itself and the consequent excluding effect of all extraneous bodies. The water of which these crystals are formed is drawn up from below by capillarity; is frozen as it comes up to the surface in vertical prismatic crystals; a new portion is drawn between the basis of the crystals first formed and the ground, which is also frozen; and so the process is continued until stopped by the failure of moisture, or the increase of the temperature due to the advancing heat of the day.

The next subject in order of which we intended to treat is that of the vapor of water in the atmosphere; but this is of so important a character in its connection with all the phenomena of the fitful changes of the weather, and the peculiarity of climate, as well as with the agricultural products of a country, that justice cannot be done to it within the limits assigned to meteorology in this Report, and therefore we shall defer it until next year. *

* [Forty-three pages of Meteorological Tables following this part are omitted in the present re-print.]

METEOROLOGY IN ITS CONNECTION WITH AGRICULTURE.

PART IV.—ATMOSPHERIC VAPOR AND CURRENTS.

(Agricultural Report of Commissioner of Patents, for 1858, pp. 429-498.)

In the preceding articles on Meteorology, it has been shown that the great motive power which gives rise to the various currents of the aerial covering of our globe is the unequal distribution of the heat of the sun; the elevated temperature of the equatorial regions heating the air causes it to ascend and flow over toward the pole, while the cold of the frigid zone produces a condensation of the air, which gives rise to downward currents in that region, and a spreading out there in all directions towards the equator.

The simplicity of this movement is first interfered with by the motion of the earth upon its axis, which gives to all the currents flowing toward the equator a curvature to the west, and to all those flowing from the equator a curvature to the east. Another perturbing influence is the unequal heating of the several parts of the different zones of the earth, consisting as they do of alternations of land and water. But the great perturbing cause is the varying quantity of moisture which exists in the atmosphere, and which by its increase and diminution gives rise to the varying conditions of the weather, and produces the fitful and almost infinite variety of meteorological changes which occur at different times and in different places.

The present essay will be principally devoted to an exposition of the phenomena of the vapor of the atmosphere, including that of the various aqueous meteors, such as rain, hail, hurricanes, tornadoes, &c. The meteorology of North America, as well as its geology, is exhibited on a large scale, and affords one of the best fields on the surface of the globe for studying the general movements of the atmosphere. The subject has received much attention on this side of the Atlantic, and a number of laborers have devoted themselves to it with ardor and success; but we regret that the discussions

which unavoidably arise among different investigators, have not always been carried on with the calmness and moderation with which the pursuit of truth should always be conducted. Indeed, meteorology has ever been a source of contention, as if the violent commotions of the atmosphere induced a sympathetic effect in the minds of those who have attempted to study them.

We have stated in the previous articles that we have no hypotheses of our own to advocate; and while we attempt to reduce the multiplicity of facts which have been collected in regard to this subject to general principles, we shall aim at nothing but truth, and endeavor to select from the various hypotheses which have been proposed, such as in our judgment are well founded on the established laws of force and motion, and which give the most faithful and explicit expression of the phenomena. We shall be ready at any time to modify or change our views as soon as facts are discovered with which they are incompatible, and indeed we shall hold most of them as provisional truths which may serve to guide our inquiries and which are to be established, modified, or rejected by the results of subsequent induction. While the general principles of meteorology are well understood, the facts relating to it on account of the variations and multiplicity of condition are the most complex of those of any branch of physical science. It has been properly said that astronomy is the most perfect of all branches of knowledge because its elements are the most simple; and we may say, for a like reason, that meteorology is the least advanced because its phenomena depend upon the concurrence of so many and so varied causes.

Vapor of the Atmosphere.

The air at all times contains water in an elastic, invisible state, called vapor. To prove this it is sufficient to pour a quantity of cold water into a bright metallic or glass tumbler, the outside of which will become covered with dew. If the vessel were pervious to the liquid we might suppose the water which appears on the outside to come from within, but this

cannot be the case with a metallic or glass vessel, and the only source to which we can refer the dew is the atmosphere. The stratum of air immediately around the vessel is cooled by contact with its sides and a portion of its vapor reduced to water. The air thus cooled becomes heavier, sinks down along the side of the tumbler, and gives place to a new portion of which the vapor is also condensed; and in this way the process is continued as long as the temperature of the water is below that of the surrounding air. If the water which trickles down the side of the vessel is chemically examined, it will be found in some cases almost entirely pure, and in others contaminated by animal and other effluvia which are diffused in the atmosphere. If the experiment be made on different days and at different seasons we shall find a greater or less reduction of the temperature of the liquid within the tumbler is required in order to produce a deposition of the vapor. The greater the number of degrees of this reduction of temperature the greater will be the evaporation from a given surface of water, and the more intense will be the different effects which depend on the relative dryness of the air. If the experiment be made in summer we shall frequently find but a small reduction of temperature necessary to produce the deposition of moisture on the outside of the tumbler, and if we attend to the state of our feelings at the same time we experience that peculiar sensation which is referred to what is called the closeness or sultriness of the atmosphere, and which is caused by the large amount of vapor with which it is charged.

The phenomena of vapor by itself in a vacuum.—To understand even approximately the effects due to the vapor in the atmosphere it is necessary that we should first carefully study the phenomena of water in an aeriform condition as it exists by itself or separated from the atmosphere; and for this purpose we may employ the ingenious method devised by Dr. Dalton, of Manchester, England, to whose researches in meteorology and other branches of physical science we are more indebted than to those of almost any other individual of the present century. He employed in these researches a

glass tube of about 40 inches in length, closed at one end, and filled with dry and warm mercury. The tube thus filled was inverted with its lower end in a basin of the same metal, and thus formed an arrangement similar to that of an ordinary barometer, in which the pressure of the air, as is well known, forces up the mercury and keeps it suspended at an elevation of 30 inches, when the experiment is made at the level of the sea. The space above the mercury is a Torricellian vacuum; that is, a space void of all gross matter, save a very attenuated vapor of mercury, which can also be removed by a reduction of temperature below the 50th degree of Fahrenheit's scale, but the correction on this account is so small that it may be neglected. Into this vacuum Dr. Dalton introduced a very small quantity of water, by forcing it from a small syringe into the mercury at the base of the column, whence it rose to the surface and was attended with an immediate depression of the mercurial column, which, when the temperature of the room was at 60°, amounted to nearly half an inch. By this experiment it was proved that water at the ordinary temperature, when the pressure of the air is removed, immediately flashes into steam or vapor, and that the atoms of this vapor repel each other, thus producing an elastic force which depresses the column of mercury. In this experiment, the quantity of water introduced was but a few grains, yet it did not all flash into vapor, but a portion of it remained in the form of a thin stratum of liquid on the surface of the mercury. Its weight, however, was insufficient to produce the observed descent of the column, and its effect in this respect could readily be calculated, since its weight was known. The descent of the mercury was therefore due to the repulsion of the atoms of vapor, and the former afforded an accurate measure of the comparative amount of this force.

The tube, as we have stated, was 40 inches long; and since the column of mercury at first occupied but 30 inches of its length, the extent of the vacuum before the introduction of the water was 10 inches, and afterward 10½ inches. That the depression of the mercury is an exact measure of the

elastic force or repulsion of the atoms of the aqueous vapor will be evident when we consider that if we remove the vapor the column will rise to 30 inches, and will then be exactly in equilibrium with the pressure of the external atmosphere, the two being in exact balance; but if after the introduction of the vapor the column is reduced half an inch in height, it is plain that the force which produces this effect must be just equal to the weight of this amount of mercury.

Dr. Dalton next diminished the length of this vacuum by plunging the lower end of the tube deeper into the basin of mercury, and thereby causing the upper end of the column to be projected farther into the tube; but this produced no difference in the height of the column, the top of which was still depressed to half an inch below the normal height of 30 inches. From this experiment we infer that the repulsion of the atoms of vapor cannot, like that of the atoms of air, be increased by external pressure; for when we attempt to coerce them into a smaller space by external pressure, a portion of them is converted into water, and the atoms which remain in the aeriform condition exert the same amount of pressure as before.

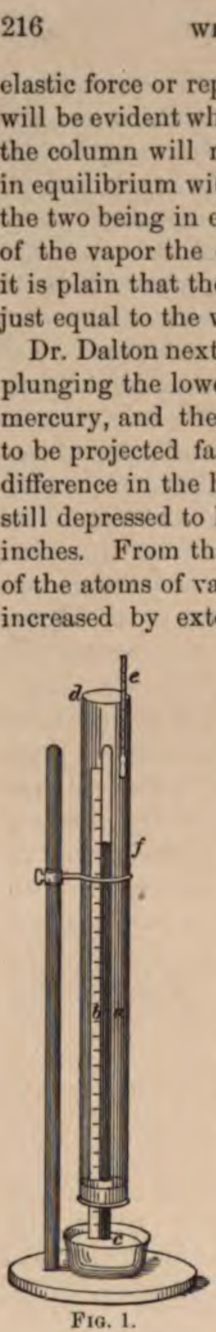


FIG. 1.

Dr. Dalton next increased the temperature by surrounding the tube containing the mercurial column with a larger tube filled in succession with water of different temperatures; this produced for each temperature a difference in the depression of the height of the column; and when the water was at the temperature of 100° the depression instead of being half an inch was almost precisely three times as much.

Fig. 1 represents the apparatus employed by Dr. Dalton, in which *a* is the barometer tube filled with mercury to the height of *f*, and its lower end plunged into the basin of mercury *c*. The grad-

uated scale for measuring the height of the column is denoted by *b*. The larger tube around the barometer tube to contain the water of different temperatures is denoted by *d*. A thermometer *e* is inserted at its upper end by which to ascertain the temperature of the enclosed water and, consequently, that of the vapor within the barometer.

With this simple contrivance Dr. Dalton made a series of experiments to determine the repulsion of the atoms of steam; or in other words, the *elastic force of aqueous vapor*, corresponding to the different degrees of Fahrenheit's scale from zero up to the boiling point. To facilitate the operations and to allow for any changes that might take place in the pressure of the atmosphere during the continuance of the experiment, another tube was placed beside the first in the same basin, and the descent of the mercurial column of the first tube estimated from the top of that in the second, which to render the measure more accurate may be effected by means of a small telescope, sliding on a graduated rod, and movable in a horizontal plane.

By placing water of a given temperature within the outer tube and gradually cooling it after each observation, and finally filling the same tube with freezing mixtures, a table similar to the following was constructed. Dalton's experiments however have been repeated with additional precautions by other scientists, and particularly by M. Regnault, from whose work the annexed table has been compiled.

A—Elastic force of aqueous vapor, in English inches of mercury.

Degs. F.	0°.	1°.	2°.	3°.	4°.	5°.	6°.	7°.	8°.	9°.
°	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
0	0·043	0·045	0·048	0·050	0·052	0·055	0·057	0·060	0·062	0·065
10	0·068	0·072	0·075	0·078	0·082	0·086	0·090	0·094	0·098	0·103
20	0·108	0·113	0·118	0·123	0·129	0·135	0·141	0·147	0·153	0·160
30	0·167	0·174	0·181	0·188	0·196	0·204	0·212	0·220	0·229	0·238
40	0·248	0·257	0·267	0·277	0·288	0·299	0·311	0·323	0 335	0·348
50	0·361	0·374	0·388	0·403	0·418	0·433	0·449	0·466	0·482	0·500
60	0·518	0·537	0·556	0·576	0·596	0·617	0·639	0·662	0·685	0·708
70	0·733	0·758	0·784	0·811	0·839	0·868	0·897	0·927	0·958	0·990
80	1·023	1·057	1·092	1·128	1·165	1·203	1·242	1·282	1·323	1·366
90	1·410	1·455	1·501	1·548	1·597	1·647	1·698	1·751	1·805	1·861
100	1·918	1·977	2·037	2·099	2·162	2·227	2·293	2·361	2·430	2·501

The first column of the above table gives the temperature of the water and vapor in the Torricellian vacuum for every ten degrees; the second, the depression of the mercury, or the elastic force of the vapor, corresponding to the several degrees of temperature of the first column. The remaining columns give the depression of the mercury for the intermediate degrees, this arrangement being adopted to save space.

For example, if we wish to know the elastic pressure of vapor at the temperature of 70°; by looking opposite to 70°, in the second column, we find 0·733 or nearly seven-tenths and a third inches of mercury. Again, if we wish the amount of repulsive force of the atoms of vapor at the temperature of 86°, we cast our eye along the line of 80° until it comes under the 6°, which is at the top of the table, and find 1·242 or very nearly an inch and a quarter as the height of a column of mercury which vapor of water will balance without being condensed into a liquid at the temperature of 86°.

By looking along the foregoing table it will be seen that equal increments of heat are attended with more than equal increments of elastic pressure. Thus while the elastic force of vapor at 20° is sufficient to depress the mercurial column a little more than one-tenth of an inch, at 40° it depresses it nearly two and a half times as much, at 60° five times, at 80° ten times, and at 100° nineteen times. The reason of this is not difficult to understand, since it is evident that the elastic pressure of the vapor must be increased by the action of two causes: First, by increasing the temperature the vapor tends to expand just as air would do under the same circumstances; and second, by the same increase of temperature a new portion of water is converted into vapor, which being forced into the same space, increases the density, and consequently the elasticity of the vapor which existed there before.

Dalton also showed that there is a remarkable difference between vapor which exists over water and vapor separated from the liquid from which it is produced. In the first case, as we have seen, every increase of temperature causes the formation of a new quantity of vapor which

serves to increase the density, and consequently the repulsive energy of the vapor previously existing. Hence, as we have shown before, the expansive power of vapor or steam increases in a geometrical ratio, while the temperature increases in an arithmetrical ratio, that is, an addition of a few degrees of heat produces more than a proportional degree of elastic force. The case however is very different with vapor separated from the water from which it is produced; it then obeys the same law as atmospheric air and increases in elasticity with equal additions of temperature.

It has been stated in a previous article that the atmosphere increases its elastic force by one four hundred and ninetieth part for every degree of Fahrenheit above the freezing point; the vapor of water follows the same law.

These facts are readily proved by the apparatus exhibited in Fig. 2. So long as any water *e* remains above the mercury in the tube *a*, the latter may be drawn up or pushed down into the reservoir without altering the height of the column of mercury *c e*. The higher the tube is drawn up, the more water will spring into vapor, while the tension or repulsive energy remains the same, as shown by the invariable height of the mercurial column. When the barometer tube is pushed down into the basin and the space above diminished, a portion of the vapor is converted into water, and this portion increases as the space is made to diminish. If however we draw up the tube so that all the water will pass into vapor, a further elevation of the tube will produce an elevation of the height of the mercurial column; the vapor will become rarified and its elastic pressure will consequently be diminished, and hence the increased length of the column of mercury. If sufficient cold and pressure could be applied to atmospheric air, it is not improbable that a portion might be con-

FIG. 2.

verted into a liquid, just in the same way that an increase of pressure converts the vapor which fills the top of the barometer tube into water. This supposition is the more probable since several gases which were at one time considered permanently elastic have been reduced in this way to a liquid by the application of a powerful pressure, combined in some cases with a reduction of temperature.

The foregoing table is limited to 100°, and is sufficient for resolving problems relative to the hygrometrical condition of the atmosphere. It is however important for the use of the steam engineer that it should be extended to a much higher degree, and accordingly experiments have been made for this purpose by a number of persons, and particularly by M. Regnault, at the expense of the French government. From the table thus extended we may see that at the temperature of 212° the elastic force of vapor balances 30 inches of mercury, and is then just equal to the pressure of the atmosphere. This fact gives the explanation of the phenomenon of boiling, since the vapor formed at the temperature of 212° has just sufficient repulsive power to expand beneath the pressure of the atmosphere, and to pass up in volumes through the water, giving it the peculiar agitation known as boiling.

It is further evident from the same table that vapor is given off from ice even at zero, or 32° below the freezing point. If a lump of this substance on a cold day be placed under the receiver of an air pump, even when the apparatus is cooled down to zero, a portion of it will immediately spring into vapor, sufficient to fill the whole capacity of the cylinder when the air is withdrawn; and if this vapor in its turn be removed by working the pump another portion of the ice will pass into the state of vapor, and if the pressure of this be removed another quantity of ice will be evaporated; and if the pumping be continued sufficiently long all the ice will be dissipated in vapor without passing through the intermediate condition of water. Instead of continuing to work the pump in order to evaporate the ice we may produce the same effect by placing within the receiver a broad dish con-

taining sulphuric acid, which will absorb the vapor as fast as it is formed.

We may convince ourselves immediately of the evaporation of ice by exposing a given weight of it during a cold day in the shade while the temperature is below freezing. It will be found sensibly, though slowly, to diminish in quantity. The same effect is exhibited in the process of drying clothes in cold weather, which though they may be stiffened by the frozen water with which they have been wetted, soon become dry and pliable by the evaporation of the ice.

The apparatus of Dalton enables us to make the following experiment, which has an important bearing on some of the phenomena of meteorology. If, while the column of mercury is at the temperature, for example, of 60°, and a small quantity of water is resting on its upper end, the space above being filled with vapor due to this temperature, we place under the lower end of the tube beneath the surface of the mercury a small crystal of common salt, it will rise through the mercury by its specific levity, and be dissolved in part or whole by the stratum of water at the top. Now as soon as this solution begins to take place we shall see the column of mercury ascend; a portion of the vapor will be absorbed, and the tension of the remainder be diminished.

In this case the attraction of the salt for the particles of water neutralizes a part of their repulsive force and thus diminishes the weight of mercury the vapor can support. For the same reason salt water boils at a temperature several degrees higher than 212°, though the vapor produced in this case has only the elastic force of that due to pure water. From the foregoing we conclude that the quantity of vapor from the surface of the ocean is less and has less tension and density than that from the surface of fresh-water lakes at the same temperature.

The table which was furnished by Dalton, and has since been corrected by more refined experiments, is of great value in various branches of science. The very simplicity of the method employed is an evidence of scientific genius of the highest character, and is well calculated to excite our admi-

ration as well as to call forth our gratitude on account of the important truths which it reveals. Dalton, although a profound thinker, and thoroughly imbued with a love of science for its own sake, was eminently a practical man in the proper sense of the term. He had not only the sagacity to frame significant questions to be propounded to Nature, but also the ingenuity to devise simple means by which the answers to these questions would be given in terms the most precise and accurate.

The weight of vapor.—There are other important questions to be answered in regard to the same subject; and the first we shall consider is the relative weight of a given quantity of vapor in a space fully saturated at different temperatures.

The general method of ascertaining the weight of a given quantity of an aeriform fluid consists in weighing a vessel of known capacity when exhausted, and again when it is filled with the air or vapor of which the weight, or in other words the density, is desired. The difference of weights of the vessel in the two conditions evidently gives the weight required. This may serve to give a general idea of the method of determining the *weight* of vapor; but it may be well to dwell a few moments on a more detailed account of one of the processes which has been actually adopted. This consists in employing an apparatus formed of a glass globe *a* (Fig. 3) screwed at *f* to the top of a barometer tube *e*. The capacity of the globe is previously ascertained by weighing it empty and afterwards filled with mercury. The difference of weight gives the weight of mercury sufficient to fill it, and from this it is easy to calculate its contents in cubic inches or parts of a cubic foot. Next, a small hollow bulb of glass *g*, is formed by the blow-pipe, and filled with a known weight of water. For this purpose the capillary tube *c* (Fig. 4, in which the bulb *g* is represented much enlarged) is plunged beneath a surface of water *b*, and the glass gradually heated by a spirit lamp *d*, by which the air

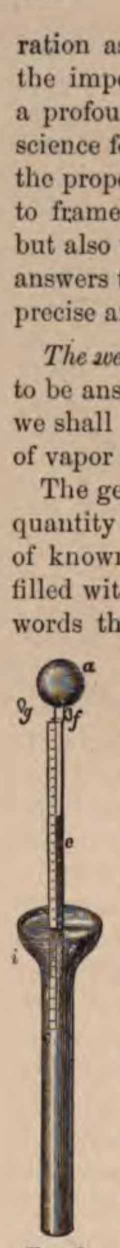


FIG. 3.

is partially expelled. It is then suffered to cool, when by the pressure of the atmosphere a quantity of water is forced up into the bulb. This is made to boil rapidly so as to expel along with the escaping steam all the air. The capillary end of the bulb being again plunged below the surface of the water, and the lamp withdrawn, the pressure of the atmosphere will now entirely fill the bulb with the liquid. The point of the capillary tube is then closed by melting it in the flame of the blow-pipe, and the bulb thus filled with water is again weighed. If from this last weight we subtract the weight of the glass we shall have the weight of the contained water. This bulb with its known amount of water is next placed in the glass globe *a*, (Fig. 3,) the long tube screwed in its place, and the whole apparatus filled with dry mercury and inverted in a basin *i* of the same metal. The mercury of course by its weight will descend from the glass globe into the tube, and sink until it becomes in equilibrium with the weight of the atmosphere, which as we have said before, will be about the height of 30 inches. The inside of the globe will then be a Torricellian vacuum, and the water if released from the small bulb in which it is contained would immediately flash into vapor by the unbalanced repulsion of its atoms; and we can readily release them from their confinement by directing upon the bulb for an instant a beam of heat from the sun by a burning glass. By this means the bulb will be broken, (particularly if formed of dark glass,) the water will be set free, and will be converted in part at least into vapor. The whole apparatus is then heated by plunging it into a water bath of which the temperature is gradually raised, or by heating the room in which the experiment is made, until all the water is converted into vapor. By carefully noting the temperature at which the liquid disappears, we have from the previous table the tension of the vapor at

FIG. 4.

this point; and since the weight of the steam which fills the globe is equal to the weight of the water originally contained in the small bulb, we have the weight of the vapor, and knowing the number of cubic inches of the capacity of the globe, we can easily determine the weight of a cubic foot of vapor at the temperature at which the experiment was made.

In this experiment care must always be taken to determine the exact temperature at which the water disappears; for if a portion of water remains in the liquid state we shall not have the true weight of the vapor; and we are assisted in determining this point by the fact that in gradually increasing the temperature of the apparatus we shall find that at the moment when all the water is evaporated the vapor will change its rate of expansion, and be governed by the same law as that of the expansion of dry air.

After having determined the weight of a given quantity of vapor, for example a cubic foot, by direct experiment according to the method we have described, the weight of an equal quantity of vapor at other temperatures may be determined by calculation. For example, the density of the vapor (as in the case of air) will be in proportion to its elastic force or the pressure to which it is subjected, if the temperature remained the same; hence from the table of elastic force already given, we may calculate the corresponding weights of a foot of vapor. The numbers thus obtained however must be corrected for the diminution of weight on account of the expansion due to increased temperature. In this way table *B* was constructed, in which the first column indicates the temperature of every ten degrees of Fahrenheit's scale; the second column gives the weight of vapor in Troy grains contained in a cubic foot of space; the remaining columns give the weight of vapor at intermediate degrees.

B—Weight of vapor in a cubic foot of saturated air, in grains Troy.

Degs. F.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
°	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr'ns.*	*Gr's.*
0	0·54	0·56	0·59	0·62	0·64	0·67	0·70	0·73	0·77	0·80
10	0·84	0·87	0·91	0·95	0·99	1·04	1·09	1·13	1·19	1·24
20	1·29	1·35	1·41	1·47	1·54	1·60	1·67	1·74	1·81	1·89
30	1·96	2·04	2·12	2·20	2·29	2·37	2·46	2·56	2·65	2·75
40	2·86	2·96	3·07	3·18	3·30	3·42	3·55	3·67	3·81	3·94
50	4·08	4·23	4·38	4·53	4·69	4·86	5·02	5·20	5·38	5·56
60	5·75	5·95	6·15	6·36	6·57	6·79	7·02	7·25	7·49	7·73
70	7·99	8·25	8·52	8·79	9·08	9·37	9·67	9·97	10·29	10·61
80	10·94	11·29	11·64	12·00	12·37	12·75	13·14	13·54	13·95	14·37
90	14·81	15·25	15·70	16·17	16·65	17·14	17·64	18·16	18·69	19·23
100	19·79	20·35	20·93	21·53	22·14	22·77	23·41	24·06	24·74	25·42

This table we shall see is of great importance in practical meteorology, as it enables us to ascertain the weight of the vapor in a given portion of the atmosphere at different temperatures.

The latent heat of vapor.—There is another circumstance in regard to vapor which is of essential importance in understanding the part which it plays in producing the diversified changes of the weather, namely, the great amount of heat which it contains at different temperatures. It is well known that the quantity of heat that a body contains is not actually measured by the thermometer or the temperature which it exhibits; for example, if a cubic foot of air at 60° be expanded without receiving or losing heat its temperature will be much diminished, because the same amount of heat which was before contained in a given space is now distributed through a larger space. If an ounce of steam from boiling water, which indicates a temperature of 212°, be condensed in water at 60°, it will give out to the latter enough heat to elevate six times the quantity of water to the boiling temperature; that is, six times as much water through 152°, or the same amount of water 912°; or in other words after having given out more than 900° of heat in the act of being converted from a vapor to a liquid, it still retains a temperature of 212°. The heat which is thus evolved, and is not indicated by the thermometer, (as has been stated in our preceding article with reference to the

melting of ice,)* is called latent heat. In thus condensing a given quantity of vapor, from water at different temperatures in a given quantity of cold water and noting the elevation of temperature of the latter, it has been shown by Dalton and others that an ounce of vapor at all temperatures contains very nearly the same amount of heat, adding the latent and sensible heat together.

This constancy of the amount of heat arises from the fact that as we increase the thermometric heat a new portion of vapor is forced into the same space, its density increases, and the amount of latent heat is diminished; hence if the attenuated vapor from ice were received in a syringe and suddenly condensed until its density became equal to that of boiling water, its temperature would be 212°.

On account of the great amount of latent heat of vapor, heat must be absorbed from all surrounding bodies during the process of evaporation; and in all cases of the reverse process, that is of the conversion of vapor into water, an equal amount of heat must be given out. This absorption of heat by vapor at the place of its formation, and the evolution of an equal amount at the place where it is condensed into water is one of the most efficient means of varying the temperature of different portions of the earth from that which they would naturally acquire under the regular periodical variation due to the changes of declination of the sun.

In the evaporation of a cubic foot of water it is known from experiment that an amount of heat is absorbed equal to that evolved from the combustion of 20 pounds of dry pine wood, and consequently every cubic foot of rain water which falls from the clouds leaves in the air above an equal amount of extraneous heat, which tends to abnormally raise the temperature due to the elevation, and to produce powerful upward currents above, and horizontal motions of the air below. We may also recall in this place the fact that water, in passing from the state of ice to that of a liquid absorbs 140° of heat, which is again evolved in the act of freezing,

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*[See *ante*, p. 195.]

and that this also is an efficient means by which colder portions of the earth are mollified in temperature.

In the explanations we have thus far given we have spoken of the increase of the repulsion of the atoms of water by an increase of heat. By this we mean the increased tendency which they have to separate from each other with a force which resembles simple repulsion, but which, if we adopt the vibratory theory of heat, will be due to the increased intensity of the oscillation of the particles. We have also employed the usual term "latent heat" to express the heat which disappears when a solid is converted into a liquid, or a liquid into a vapor—though this, according to the new theory of heat, would be expressed by the quantity of vibration or mechanical energy which is absorbed in the change of state of the body and which will re-appear when the reverse process takes place. To illustrate this suppose an upward impulse be given to a ball sufficient to throw it upon a shelf. In this case we may consider the mechanical energy as having been expended in producing this effect, although it is ready again to make its appearance and to do work when the ball is suffered to fall again to the level whence it was projected.

Vapor in air.—We are also indebted to Dr. Dalton for another important series of experiments which relate to the mingling of air and vapor. In the experiments before given the vapor was weighed, and its temperature and tension determined in a separate state and unmingled with the air. To ascertain the effect which would be produced on the tension of vapor when suffered to be exerted in a space already occupied with air of different densities, Dr. Dalton employed the same method of experimenting previously described. A barometer tube was filled and inverted, as before, in a basin of mercury, a quantity of air was then admitted, which rising into the Torricellian vacuum, pressed by its elasticity on the surface of the mercury and caused it to descend a given number of divisions of the scale which were accurately noted; a small quantity of water was next admitted, which rising to the top of the mercurial column was after a

few moments in part converted into vapor while the mercury was observed to be depressed. When the experiment was repeated with different quantities of air above the mercurial column and at different temperatures, produced by varying the heat of the water in the external tube, or which would amount to the same thing, by varying the temperature of the room, the remarkable fact was discovered that the depression of the mercurial column due to the introduction of the water was precisely the same at the same temperature as when the experiment was made with a vacuum; for example, at the temperature of 60°, whatever might be the elasticity of the air within the tube, the introduction of the water always gave an additional depression of half an inch. From this result the important fact is deduced that the tension or elastic force of vapor in air is the same as that of vapor in a vacuum; from which we might also infer that the quantity of vapor which can exist in a given space already occupied with air is the same as that which can exist in a vacuum at the same temperature. But this fact may be directly proved by an independent experiment. For this purpose let the globe *a*, Fig. 3, be filled with air, while the small bulb placed within contains a known quantity of water, and let the globe thus filled be screwed to the top of the barometer tube. If the apparatus be now partially filled with mercury so as to leave the globe nearly filled with air and the whole inverted with its lower end in a basin of mercury, the mercury will descend along the scale and will come to rest at a certain division, which will indicate the elastic force of the air in the globe; if next the stopcock be shut and the small ball be broken by the heat from a burning glass the contained water will, in part at least, spring into vapor; and if we gradually heat the globe until all the water disappears and note the temperature at which this takes place, the globe at this moment will be filled with air at a known density and with in-

FIG. 3.

visible vapor of a known weight and temperature. If we calculate from the table B, (p. 225,) the amount of vapor which at this temperature existed in this globe while its interior was a vacuum, we shall find it precisely the same as the weight of that which the globe now contains when filled with air. If, for example, the globe be a foot in capacity and the small bulb contain 9·37 grains of water, the temperature at which the water disappears being 75°, by passing our eye horizontally along the table we shall find under 75° the same number of grains. This experiment conclusively proves that the same amount of vapor can exist in a space already filled with air as in a vacuum. The repulsive atoms of each however will be exerted against the sides of the vessel, and the resulting pressure will be the sum of the two; a fact which is proved by noting the height of the column e, which indicates the elastic pressure of the air in the globe before the vapor was admitted, and which, for example, we may suppose to be equivalent to the weight of 20 inches of mercury. If we now open the stop-cock the mercurial column will be depressed by the additional repulsion of the atoms of the vapor of water, and if the temperature be at 75° (as we have previously supposed) the depression will be 0·868 inches.

The same result may be obtained by the following method, which also gives us an independent means of determining directly the amount of vapor which exists in the atmosphere at a given time, and which may be employed for verifying the results obtained by other means. Let a tight cask furnished with a stop-cock near its lower part be entirely filled with water, and let the small end of a tube which has been drawn out in a spirit lamp be cemented into the vent-hole above, so that no air can enter the cask except through the tube. Let this tube be filled with coarsely powdered dry chloride of calcium—a substance which has a great affinity for moisture—and the upper end put in connection with an open vessel containing air entirely saturated with moisture, which can readily be effected by agitating a quantity of the liquid in the vessel from which the air is drawn. Let the

stop-cock be now opened and exactly a cubic foot of water be drawn into a measured vessel; it is evident that precisely a foot of air will enter the top of the cask through the tube and between the interstices of the pieces of chloride of calcium, the moisture will be absorbed, and its weight can be accurately ascertained from the increase of weight of the tube and its contents, which had previously been weighed for that purpose. By this simple experiment as well as by the one we have previously given we are enabled to conclusively prove that the weight of vapor contained in the air in a given space is the same as that which would exist at the same temperature in a vacuum. To render the result of this experiment absolutely perfect however a slight correction must be made on account of the expansion of the air and the vapor due to the increased repulsive energy of the compound over that of the air itself. This will be evident from a due consideration of what follows.

If into an extensible vessel, such as an India-rubber bag filled with air, a little water be injected, the bag will be suddenly expanded by the additional repulsive force of the atoms of vapor. Previous to the introduction of the water, the bag will be pressed equally on the outside and on the inside; on the former by the weight of the external atmosphere, and on the latter by the repulsive or elastic force of the atoms of the inclosed air; when the water is introduced and a portion of it springs into vapor the elastic force of the aqueous atoms must be added to that of the atoms of the air, and the interior will then be pressed outward with a force equal to the sum of the two repulsions. For example, if the experiment be made at 60° and the air at its normal weight, the outward pressure within the bag previous to the introduction of the water will be equal to 30 inches of mercury, but after the water is injected it will be 30 and a half inches; hence expansion will take place and the bag will be distended until by the separation of the interior atoms the repulsion is so much weakened that the pressure without and within will again be equalized. The amount of the increase in bulk will be given by the following propor-

tion: as the pressure of 30 inches of mercury is to the pressure of 30½ inches, so is the original bulk of the India-rubber bag to its bulk after the introduction of the vapor.

From the preceding experiments and observations it is evident *that in free air the vapor exists as an independent atmosphere, being the same in weight and in tension as it would be in a vacuum of the same extent and of the same temperature.* That the same amount of vapor can exist in a space filled with air as in a vacuum at first sight appears paradoxical, but when we consider that a cubic inch of water expanded into steam at 212° occupies nearly 1,700 times the bulk which it does in the form of water, also that air may be compressed into a space many hundred times less than that of its ordinary bulk, it is evident that the extent of the void spaces is incomparably greater than the atoms themselves, and consequently it is not difficult to conceive that the atoms of the vapor have abundance of space in which to exist between the atoms of air and the atoms of air between those of vapor. Dalton announces this important truth by stating that air and vapor and almost all gases are vacuums to each other. This enunciation is a true expression of the state of diffusion which gases and vapors attain after the lapse of a given time, but it does not truly express the phenomena of the act of diffusion. In a perfect vacuum a given space is filled with vapor almost instantaneously, or with a rapidity which has not yet been estimated, but this is not the same in a space already filled with air. In this case, though the vapor ultimately diffuses itself through the air as it would in a vacuum, yet time is required to produce this effect; the result is as if there were a mechanical or some other obstruction to the free passage of vapor through the different strata of air, and indeed it would appear from the following experiments that a definite force similar to that produced by a slight attraction or repulsion is offered in the resistance of a given thickness of this medium: In the laboratory of the Smithsonian Institution a glass tube of about 3 feet in length, closed at its lower end, suspended vertically, and containing about an inch of water, has re-

mained for several years undisturbed in this condition without the least perceptible diminution in the amount of the liquid. In another experiment a pane of glass was removed from an external window of a room and the place of the glass supplied by a board, through the middle of which a hole of about an inch in diameter was made, and in this opening a tube was placed horizontally, one end being in the room and the other in the outer air. To each end of this tube a glass bulb was attached, air tight, the one within the room containing about an ounce of water, while the tube and the bulb on the outside were occupied with air. The temperature of the air within the room was on an average about 70°, while that of the air without was on an average nearly 32°, and although the experiment was continued for several months during winter not one drop of water was distilled over into the outer bulb. When however the latter was surrounded by a freezing mixture a small quantity of vapor did pass over and was condensed into water; and also when the vapor in the outer bulb was absorbed by introducing a quantity of strong sulphuric acid into this bulb the water in the other bulb gradually diminished in weight.

From these experiments it would appear that there is more than a mechanical obstruction to the transfusion of vapor through air, and that if the difference of tension of vapor in two vessels only amounts to a certain quantity no transfusion from one will take place to the other, or in other words for each inch or foot of thickness of a stratum of air a certain amount of unbalanced repulsive energy is required for transfusion. The rapid mingling of vapor with air is due in a considerable degree to the currents produced by the mixture itself and by variations of temperature.

From an application of the principle relative to the coexistence of vapor and air, above given, we are able by means of tables *A* and *B* to immediately ascertain by inspection the amount of vapor which exists at any time and in any place in a foot of air perfectly saturated with moisture and its tension; that is, which contains as much vapor as it can hold at the given temperature. If for example the tem-

perature of the saturated air be 75°, we would find opposite this, in table *B*, (p. 225,) the weight of 9·37 grains; and by merely knowing the temperature at other times and at other places we would be able to determine the relative quantity of the vapor under these different circumstances and to form a judgment as to the dryness or humidity of different localities; but since there is a constant resistance to the diffusion of vapor through the atmosphere it follows that the air is seldom at any time or in any place entirely saturated. It is on the contrary in the condition of air filling a vessel into which less water has been injected than that necessary to furnish sufficient vapor to fill the interstices between the atoms at the given temperature.

We have been provided by Dalton with a very simple process by which the amount of vapor in a given portion of air which is not saturated can be determined. For this purpose it is only necessary to procure a bright metallic tumbler, the thinner the sides of which the better, and partly filling this with water at the temperature of the air and gradually adding colder water, stirring the mixture all the while with the bulb of a delicate thermometer, note the temperature at the moment when dew begins to be deposited on the outside. This temperature is called the dew-point, from which we determine by the tables the tension and the amount of vapor in the surrounding atmosphere. To render this clear, suppose the amount and tension of vapor in the atmosphere to be that which would be produced by a temperature of 60°, the temperature of the air at the time of the experiment being 70°, the atmosphere in this case would not be saturated; but if we should gradually cool it down to the temperature of 60°, it would *then* be saturated, and the least diminution of temperature below this degree would cause a precipitation of vapor in the form of mist or dew, and this is what really takes place in regard to the vapor which immediately surrounds the sides of the tumbler. The introduction of cold water into the tumbler cools the surface, which in turn cools the air immediately around it, and when the diminution of temperature reaches the point at which

the air is just saturated the dew makes its appearance. Hence when the sides of the vessel are very thin the temperature noted by the thermometer within gives that of the dew-point without, and if we inspect the table for this temperature we find at once the corresponding tension and weight of vapor in that portion of the atmosphere in which the experiment was made.

It is not however upon the actual amount of vapor which the air contains at a given time or place that its humidity depends; but upon its greater or less degree of saturation. That air is said to be dry in which evaporation takes place rapidly from a surface of water or moistened substance. In an atmosphere entirely saturated with vapor, that is in one which is filled with as much vapor as the space which it occupies can contain, the vapor already in the air by its elastic force presses on the surface of the moist body and neutralizes the repulsive action of the water; if however the temperature be raised, the elastic force will be increased, and a new portion will be forced into the same space; the farther therefore the condition of any portion of air is from saturation the more rapid will be the evaporation from the moist bodies which it surrounds.

For example, a portion of saturated air at a temperature of 102° would contain vapor of an elastic force equal to a pressure of 2 inches of mercury. (See table *A*, p. 217.) If the same air however contained vapor of only the elastic force of 59°, (that is if the dew-point were at 59°,) the elastic force would be half an inch, and consequently there would be a force unbalanced by the pressure of vapor equal to the pressure of a column of 1½ inches of mercury. The dryness therefore of the air is estimated by the difference of the elastic force of the vapor due to the temperature of the air, and of the elastic force due to the tension of the dew-point.

In meteorological works generally, a portion of the atmosphere containing vapor equal in tension to that of the temperature of the air is said to be fully saturated, and its humidity is marked 100; but if the elastic force of the air as determined by the dew-point is only one-fourth of that

necessary to produce complete saturation, the relative humidity is marked 25. To find then the relative humidity at any time, we seek from the tables the tension of vapor due to the temperature of the air, and again its tension due to that temperature to which it must next be cooled down in order to produce precipitation, or full saturation, which temperature as we have seen is that of the dew-point. We then say, *as the tension of the first temperature is to* 100, *so is the tension of the other temperature to the percentage of saturation.* In this way comparative tables of relative humidity for different places are calculated from actual observation.

Instead of employing the method of the dew-point for ascertaining the quantity of vapor in the atmosphere, a process which is attended with some difficulty, particularly in cold weather, since in this case it is not easy to reduce the temperature of the water within the tumbler except by a freezing mixture sufficiently low to produce the deposition of dew, another process has been employed, called that of the wet and dry bulb thermometer.

In this process we note the temperature of the air by an ordinary thermometer, and again we observe the temperature to which in the same place a thermometer, whose bulb is covered with wet muslin, descends. If the air is perfectly saturated with moisture the two thermometers will indicate the same degree; but if the temperature is above that due to the elastic force of the actual amount of vapor in the air the evaporation from the moist bulb will cause it to descend, by the absorption of heat, a certain number of degrees below that indicated by the naked bulb.

M. Regnault has compared by direct experiment, the indications of the wet and dry bulb thermometer, with the actual amount of vapor contained in air at different temperatures and at different degrees of saturation, according to the method previously explained, and has in this way formed a series of tables by which the dew-point, the tension of the vapor, and the weight in a cubic foot can be ascertained. In order however that these indications may be relied upon, it is necessary that the observations be made with care, since the evaporation from the wet bulb will very

much depend, as we shall presently see, upon the motion or stillness of the air; and indeed we think that in all cases, in order to obtain comparable results, the bulb should be fanned, so as in every instance to give the same amount of agitation to the surrounding medium. This will be evident from what we have said of the slow diffusion of vapor of feeble tension in the atmosphere. A local atmosphere of vapor is soon formed around the bulb, which very much impedes evaporation and consequently the reduction of temperature.

Evaporation of water.—Water is constantly evaporated from the surface of the ocean; the amount however diminishes as we proceed from the equator towards the poles. It is also exhaling from the surface of the earth, but in less quantities. The daily, monthly, and yearly amount of evaporation from a given surface of water and different kinds of earth is one of the most important data in reference to engineering and agriculture which can be furnished, and we would commend the research in reference to it to the special attention of any person who can command the time and desires an opportunity of advancing our knowledge of the operations of nature. A series of experiments on the evaporation from water may be made by carefully noting the quantity which disappears daily from a surface of a square foot freely exposed to air and sunshine. The depth of the box, which may be of tin encased in wood, should be 6 inches, and the amount of water measured by a screw, the lower end of which tapers to a point, and on the upper end a divided circle is placed, so marked that the tenth part of the width of the screw or the one-thousandth of an inch may be estimated. Care should be taken to guard this surface from rain, and in high wind to estimate the amount of water which may be blown out; the latter may be approximately found by surrounding the evaporating vessel with a border of gray paper, on which each drop of escaping water will make a stain; the number and size of these spots being known, the amount of water blown out may be estimated from the result of previous experiments in which the known quantity of the fluid has been sprinkled over the same surface. It is well, in order to make certain corrections, to observe the

average temperature of the water during the day, and for this purpose a bulb of a thermometer is placed just below the surface of the liquid. In ascertaining the evaporation from different kinds of soil, a number of boxes of the dimensions above described, should be filled with different samples, supplied with a measured quantity of water, weighed from day to day, and the loss (which will give the evaporating capacity) accurately noted. To ascertain the amount of evaporation from the actual surface of the earth in the course of the year, the loss should be daily determined from a new portion of earth taken from the surface in its actual condition.

The annual amount of evaporation from a given surface of water in the interior of the country is greater than that of the rain which falls on the same surface, but the amount of evaporation from the surface of ground is generally less, particularly in mountainous districts.

The evaporation does not depend upon the position of the evaporating surface since a piece of moist paper pasted on a pane of glass loses the same amount of water in the same time, whether it be held horizontally or vertically. It does however depend very much upon the nature of the surface; for example, less must be given off in a given time from a surface of salt water than from a surface of fresh water; and also from the cohesion with which water adheres to solids, a less amount of vapor is produced in a given time from a given surface of moist earth than from water, as is shown by the following table, deduced from observations made by M. Gasparin, in France, at temperatures from 73° to 75° F., during the time specified:

Dates.	Evaporation from water.	Evaporation from earth.
	Inch.	*Inch.*
1st day of August	0·575	0·160
2d do.	0·534	0·098
3d do.	0·448	0·070
4th do.	0·468	0·051
5th do.	0·456	0·051
6th do.	0·429	0·047
7th do.	0·367	0·051

The surface of the earth in this experiment was at first completely soaked with water.

It is evident, on account of the slowness with which vapor diffuses itself through still air, that a much greater evaporation will be produced during a brisk wind, particularly if it be from a dry quarter, than during calm weather. If the vapor which is formed is allowed to accumulate over the evaporating surface, it will by its re-action retard the free ascent of the other portions of vapor; but if it be constantly removed as fast as it is formed the process will evidently go on more rapidly.

Vapor as we have seen contains a large amount of latent heat, and water cannot be converted into an aeriform state without the supply of the necessary quantity of this principle. Hence the higher the temperature, or the more freely the evaporating surface is supplied with heat, the greater will be the amount of vapor in a given time.

We have seen that water immediately flashes into vapor in a vacuum, and we might infer from this that the rarer the air, or the more nearly it approximates to a void, the less obstruction would it offer to the free production of vapor, and the correctness of this inference has been satisfactorily shown by direct experiment.

We owe to Dalton a series of precise experiments on the evaporation of water in air of different degrees of dryness and at different temperatures. He employed in his investigations a circular dish or pan 6 inches in diameter, about an inch deep, and suspended from the beam of a balance, by which the loss of water could be accurately ascertained from the variations of the weight in a given time. With this instrument he made a series of experiments while the air contained different quantities of moisture, the amount of which was ascertained by means of the dew-point method we have before described in a perfectly still place and with the apparatus exposed to a rapid draught of air. At the boiling point the evaporation in still air was 120 grains in a minute; in a gentle wind, 154 grains; and with a strong wind, 189 grains. A similar difference existed at the evaporating temperature

of 60°: in still air the evaporation was 2·1 grains in a minute; in a gentle wind, 2·7; and in a strong wind, 3·3. From all the experiments he deduced the important result that the amount of evaporation in all cases is proportional to the difference of the elastic force of the temperature of evaporation and that of the dew-point or the vapor actually in the air.

The empirical rule deduced from his table of results will serve approximately to calculate the amount of evaporation under the different conditions of temperature, dryness, &c., of the air, the temperature of the evaporating surface, and that of the dew-point being known. For still air multiply the difference of the tension of vapor due to the temperature of the evaporating surface, and of the vapor in the atmosphere, by 4, and this will express in grains the weight of the vapor given off from a circular surface of water of 6 inches in diameter in one minute of time. If a gentle wind be blowing multiply the same difference by 5, and if a high wind exists during the experiment multiply the same difference by 6. If for example the temperature of the evaporating surface be at the boiling point, and the temperature of the dew-point be 60°, we shall have 30 inches, the tension of the evaporating surface, and 0·5 for that of the tension of the vapor in the atmosphere at the time, the difference will be 29·5, which multiplied by 4 gives 118 grains. Again, if the temperature of the evaporating surface be 90, and that of the dew-point 70, then we shall have $1·4 - 0·7 = 0·7$. If we suppose a gentle wind blowing at the time this must be multiplied by 5, and we shall have $0·7 \times 5 = 3·5$ grains as the amount of evaporation per minute from a circle of 6 inches in diameter.

The formula of Dalton, in the absence of other data, may be considered a valuable approximation; still results derived from direct observations in different parts of the earth, as we have said before, are desiderata of great value.

Physical effects of vapor in the atmosphere.—Before considering the more important meteorological changes produced in the general condition of the atmosphere by the vapor which

it contains, we may discuss some of the minor physical phenomena connected with the process of evaporation and the existence of water in an aeriform condition.

Heat and moisture are the principal essential atmospheric agents in the production of vegetable matter, and where these are not found in sufficient quantities, however rich may be the soil in fertilizing materials, at least comparative if not absolute sterility must prevail. Unfortunately however, these conditions though so highly favorable to the production of the substances which administer to the necessities and conveniences of life, are not equally favorable to the condition of health of the more highly civilized races of men. Heat and moisture are also the essential conditions under which the deadly malarious effluvia exert their baneful influence—especially upon the white race; and though science may hereafter furnish the means of disarming them of their terrors, yet at present they require the rich harvests of fields which would otherwise be uncultivated, to be reaped by the labor of individuals of another race so different in their physical organization as to be apparently exempt from the effects of these aerial poisons. The fertile rice, cotton, and sugar fields of the southern portion of the United States, are cultivated by negroes not only with impunity but without impairment of their physical enjoyments of life.

The relative moisture of different countries is intimately connected with their condition as to healthfulness. While in the moist climate of Great Britain and that of some of the West India islands diseases of the lungs are prevalent, they are seldom known in the dry regions of Nebraska and Minnesota.

From the experiments of Dalton, as we have seen, the rapidity of evaporation is proportional to the difference of elastic tension of the vapor in the air and that of the evaporating surface. Meteorologists have generally adopted as the expression of relative humidity the ratio of the force of vapor in the air to the force which it would have were it perfectly saturated, or they sometimes adopt an equivalent expression by defining the relative humidity to be the ratio of the absolute

quantity of vapor which the air could contain at the given temperature, to that which it actually contains. According to this definition two places would be equally damp which are both half saturated with vapor, though the abstract quantity of vapor in the one case may be many times that of the other. Thus in winter when the temperature is very low and the absolute quantity of vapor in the air is exceedingly small, the air may have a maximum of dampness, that is to say, a very great relative humidity. Although this method of establishing the relative humidity of different places may correspond with variations in different phenomena, yet there are some effects which appear to depend not on the relative but on the absolute amount of humidity in the air. The conducting capacity for electricity (for example) appears to increase with the absolute amount of vapor in the air, and hence experiments with the electrical machine succeed much better in winter than in summer, though the relative humidity in both cases may be the same. Again, since the temperature of our bodies is about 98°, and as this may be regarded as the temperature of an evaporating surface, the difference of tension of vapor from the pores of the skin and that in the air must be very different in winter and in summer; and hence in the latter case, when the dew-point approaches the temperature of the body, we experience the sensation of the closeness and sultriness of the atmosphere.

On the other hand the intense cold which is felt on the Western plains in winter is due principally to the rapid evaporation from the pores of the skin—a result which can only be guarded against by a covering of close texture, such as the prepared skins of animals. In this connection we may mention a fact, which at first sight might appear to militate against the usages of civilized and refined life, namely, that dirt and grease are great protectors of the skin against inclement weather, and therefore, says Mr. Galton, "the leader of a party should not be too exacting as to the appearance of his less warmly clad followers." Daily washing, if not followed by oiling, must be compensated by warmer clothing. A savage never washes himself in cold weather unless he

can give himself a clothing of grease. The tendency to evaporation from the skin during high winds must be opposed by a substance which will partially close the minute orifices. Warmly clad and protected from the cold of winter the civilized man can enjoy the luxury of washing which is denied to the naked savage.

Among other effects of evaporation connected with its reduction of temperature, should be mentioned the advantages derived from draining marshy soil, that the cooling due to the evaporation of the surface water, is thereby diminished. It is said that the mean temperature of certain parts of England has been perceptibly increased by the general introduction of this system of agricultural improvement.

The moisture of the atmosphere often affects our health and comfort by its deposition on the walls and other parts of our habitations. It is absorbed with great force and in large quantities into the pores of almost every substance, and is given out again when a change in the temperature or dryness of the air occurs. Building-stone and brick absorb a large amount, which may be transmitted by capillarity from without through a wall of considerable thickness and evaporated at the interior surface. The dampness however of a stone house is not principally due to this cause, but to the deposition of moisture from the air on the cold surface of the wall—precisely analogous to the formation of dew on the surface of a pitcher containing cold water.

If during a period of cold weather an apartment of a stone house has been closed, and on the recurrence of a warm day the windows are opened to air the room, the deposition we have mentioned takes place in abundance, and the result intended to be guarded against is promoted rather than diminished. If a fire be made in the room previous to opening the windows, so that the sides of the apartment may be made warmer than the air, the deposition will not take place. The effects both of the transmission and of the deposition of moisture can in a great measure be obviated by the means now generally adopted of lining the interior of the room with a thin coating of a non-conducting material separated

from the wall by a stratum of air. The surface of this material readily assumes the temperature of the air, and therefore does not allow of the deposition of much moisture. This internal lining, known by the name of furring, is usually composed of lath and plaster, but in some large buildings it is formed of a single thickness of brick, which prevents transmission of moisture from without, but does not fully obviate the tendency to deposition within, since a large amount of vapor is absorbed through the pores of the coating of plaster into the substance of the brick and again given out with a change of temperature.

The dampness of newly-plastered walls is in part due to a chemical action, which (paradoxical as it may appear) is not obviated by heating the wall. After a newly plastered room has been dried by an excess of artificial heat, it continues for a long time to give off vapor, and this is due to the chemical change going on while the lime in the plaster is in process of being converted from what is called a hydrate to a carbonate of lime. Perfectly dry slacked lime contains in chemical combination a portion of water, and when it is exposed to the atmosphere it absorbs carbonic acid from the air and expels the water in the form of vapor; hence, after a plastered wall has been thoroughly dried it ought to be exposed freely to currents of air, which may furnish the carbonic acid necessary to expel what may be called the solid water or that of chemical combination.

The water which is absorbed into the pores of stone by capillary attraction does not change its dimension. Mr. Saxton, of the Coast Survey, has shown that a rod of marble of 3 feet in length is not increased the ten-thousandth part of an inch by soaking it in water from a state of perfect dryness produced by heating it in an oven. The experiment was made on the marble of the Capitol, at the request of Captain Meigs, the superintendent of the extension of that national edifice. The absorption of moisture by organic substances however produces a change in their dimensions, which takes place with the exhibition of great force. The water is absorbed in great quantities at the ends of the

fibres of wood, and the principal expansion takes place in a direction at right angles to these fibres; it is also absorbed laterally between them, though in a less quantity. The warping of furniture is simply due to the exhalation of the water in the form of vapor from the pores of the wood and the consequent shrinking of the part from which the exhalation has taken place, while the other parts retain their original bulk. To prevent this it is necessary to imprison the vapor by a coating of an impervious substance, such as varnish or paint, or what is still better to expel the moisture by baking the wood and subsequently filling its pores with some resinous substance. It is important however to observe that when a substance is to be protected from moisture by a covering of paint or varnish, care should be taken to cover every part with the impervious mixture, for the moisture may be drawn in through even a nail hole and pervade the whole interior capacity of the wood.

Various instruments for indicating the moisture of the atmosphere without accurately measuring its changes have been constructed upon the principle of the absorption and consequent change of dimensions of different substances. An instrument, which has lately been very widely described in the newspapers under the erroneous name of a simple barometer, is composed of two shavings of light wood glued together so as to make a ribbon of double thickness; the fibres of one layer being at right angles to those of the other. The absorption of the moisture into the shaving in which the fibres are lengthwise tends merely to increase the width and not the length of the compressed ribbon, while the absorption of moisture into the shaving of which the fibres are transverse tends to increase the length of the ribbon and thus causes it to curl. The foregoing instrument belongs to the class denominated hygroscopes, intended simply to indicate the changes which take place in the vapor in the atmosphere without furnishing the means of measuring its precise amount. For this purpose various substances are employed, such as a stretched cord, a human hair deprived

of oily matter by washing it in ether, and the beard of the wild oat; the change in length of the first two and the twisting of the latter furnish the indications required.

Different materials absorb moisture in different degrees; a fact which is evident in passing along the sidewalk of a street at the beginning of a rain. While some of the bricks of which the pavement is composed are entirely wet at the surface others appear dry, because the water which has fallen upon them has been absorbed. It is scarcely necessary to add that after perfect saturation has taken place, and the surface is exposed to the heat of the sun, the appearance of wetness is exhibited in a reverse order. The relative absorptive power of different materials is frequently a matter of considerable practical importance, which can be readily ascertained by weighing equal bulks of the material previously dried in an oven, and again after having been thoroughly soaked under the pressure of several feet of water. The absorption of water and its subsequent expansion by freezing is the most efficient agency in the gradual destruction of the architectural monuments by which the ancients sought to impress upon the future a material evidence of their power and wealth.

Constitution of clouds.—Water in the state of vapor (as has been stated,) is perfectly transparent, and this may be conclusively proved, even of steam at a high temperature, by boiling water in a glass vessel with a long neck or by fastening a glass tube to the spout of a tea kettle. The vapor within the glass will be entirely invisible, and that peculiar condition called *cloud* will not be assumed till the transparent steam mingles with the cooler atmosphere and is partially condensed. The appearance of a cloud is also produced if a portion of transparent air is suddenly cooled, either by expansion or mingling with a portion of air of a lower temperature. Much speculation has arisen in regard to the nature or condition of water when in the intermediate state of cloud, and though the subject has occupied the attention of scientists for more than a century it is still not fully settled.

Saussure, the celebrated Swiss meteorologist, states that in

ascending the sides of a mountain into the region of the clouds he has seen globules of water as large as small peas floating in the air, which from their levity were evidently hollow spheres, similar to small soap bubbles. From this observation the idea became prevalent that the water of a cloud was in a vesicular condition, or in other words that cloud consists of minute hollow spheres of liquid water filled with air which is rendered more buoyant by the rarefaction due to the heat of the sun; and this opinion was strengthened by the fact that clouds do not give a decomposition of the rays of light sufficient to exhibit the phenomena of the rainbow. In what manner such a condition of water can be produced and how it can be retained, has not, so far as we are informed, been explained by any principle of science. A soap bubble soon becomes too thin to retain its globular form, and is resolved into the condition of soap water. Ordinary water is still more unstable and cannot be retained for an instant in a hollow spherical form. We shall therefore be on the safe side if we adopt an hypothesis apparently more in accordance with known and established principles, and if this does not furnish a logical account of all the phenomena we must wait until further research or light from collateral branches of science dispels the obscurity with which this point may be involved.

The suspension of the clouds can be explained by taking into account the extreme minuteness of the particles of which they are composed. In the case of mists which are sometimes formed at the surface of the earth and afterwards become clouds in being elevated into the atmosphere by a wind blowing between them and the earth, the particles are of such extreme tenuity as to be invisible to the naked eye, and their presence is rendered evident only by looking through a stratum of considerable thickness.

If particles of lycopodium (the sporules or seeds of the club-moss) are dusted upon a flat glass they exhibit a series of colors, when held between the eye and the light, produced by the interference of the waves of different rays of light. In order to produce this effect, the particles of lycopodium (as can be proved

mathematically) must not exceed the seven-thousandth of an inch in diameter. Now the particles of a cloud are sometimes known to present the appearance of similar colors, and therefore are not larger than those of the lycopodium. This extreme minuteness is sufficient to account for the suspension of clouds or the extreme slowness with which they descend. M. Maille of Paris has attempted to compare the volume of a particle of this size with that of a drop of rain water of about a tenth of an inch in diameter. He finds that it would require upwards of 200 millions of particles of cloud to make one drop of rain water of the size mentioned. We are prepared to admit the correctness of the conclusion when we reflect on the rapid increase of the volume of a sphere relative to the increase of its diameter. For example, if a series of spheres have diameters in the ratio of 1, 2, 3, 4, 5, 6, the volumes or weights of the spheres, provided they are of homogeneous material, will be represented by the numbers 1, 8, 27, 64, 125, 216. Indeed nothing is more deceptive than the estimate we form of the relative volume or weight of different solids by simply comparing their diameters. It requires but a very small increase in the diameter of an egg, for example, to double its weight. We know that the resistance of the air to the descent of a falling body is in proportion to the surface which it presents to the resisting medium. Now every time a drop of water is divided, a new surface is exhibited, and when the division is carried as far as that of the particles of cloud, the resistance must be so great that an indefinite length of time must be required to produce a descent of a few hundred feet.

The process of the formation of clouds will be described in a subsequent section; we may here however mention that the forms and aspects in which they are presented are indicative of the circumstances in which they are forming or dissipating, and hence the importance of giving special names to these forms in order that they may become objects of definite study. The first attempt at a descriptive classification of clouds was by Mr. Luke Howard in 1802. An account of this is given in all works on meteorology, and we need here

only give a brief exposition of his nomenclature. He divides clouds into three primary modifications: cumulus, stratus, and cirrus, with intermediate forms passing into one another under the names cumulo-stratus, cirro-stratus, cirro-cumulus; and lastly, a composite form, resulting from a blending or confusion of the others, under the name cirro-cumulo-stratus or nimbus.

1. *Cirrus*, consisting of parallel or diverging fibres, extended by increase of material in any or in all directions.

2. *Cumulus*, convex or conical masses, increasing upward from a horizontal base.

3. *Stratus*, a widely extended continuous horizontal sheet.

4. *Cirro-cumulus*, generally known as "mackerel sky," consisting of small rounded masses, disposed with more or less regularity and connection.

5. *Cirro-stratus*, consisting of horizontal or slightly inclined masses, undulating or separating into groups, giving the idea of a shoal of fish in the distance.

6. *Cumulo-stratus* consists of a blending of the cirro-stratus with the cumulus.

7. *Nimbus* is the cloud from which a continued rain falls.

A drawing of these different forms of clouds will be found in the instructions for meteorological observations published by the Smithsonian Institution.

Dew and hoar frost.—When a mass of moist air is brought in contact with a cold body its vapor is condensed into water and deposited in minute globules on the cooled surface, which constitute dew. If the temperature of the surface is below the freezing point the globules of water will be frozen into minute crystals of ice, which constitute hoar frost. For a long time the nature of these phenomena was entirely misconceived; the effect was put for the cause, the dew being regarded as producing the chill which accompanies its formation instead of the reverse. Dr. Wells of London, born in South Carolina, was the first who gave the subject a scientific investigation, and by a series of ingenious, accurate and

conclusive experiments furnished a definite explanation of all the phenomena. They are simply due to the cold produced in different bodies by radiation. As we have seen, the earth is constantly radiating heat into celestial space, and is constantly receiving it from the sun during the continuance of that body above the horizon. As long as the heat from the sun exceeds that radiated into space the temperature of the surface of the earth and that of the air in contact with it continues to increase; but when the two are equal the temperature remains stationary for a short time and then begins to decline as the heat of the sun, on account of the obliquity of the rays, becomes less than the radiation into space. The maximum of heat generally takes place between 2 and 3 o'clock in the afternoon, and the cooling from this point goes on until near sunrise of the next morning. As soon as the sun descends below the horizon the cooling of the surface of the earth takes place more rapidly if the sky be clear; the air in contact with grass and other substances which are cooled by this radiation will deposit its moisture in a manner analogous to that of the deposition of water on a surface of a metallic vessel containing a cold liquid. Although the atmosphere may contain the same amount of vapor, yet the quantity of dew deposited during the night in different places and on different substances is very unequal. It is evident that it must depend to some extent upon the quantity of moisture, since if the air were dry, no deposition could take place; and indeed it has been remarked that on some parts of the plains west of the Mississippi dew is never observed. It must also depend upon the clearness of the sky; for if the heavens be covered with a cloud the radiant heat from the earth will not pass off into celestial space, but will be partly absorbed by the cloud and radiated back to the earth. This is not a mere hypothesis but has been proved by direct experiment. The author of this article while at Princeton some years ago placed a thermo-electric apparatus in the bottom of a tube provided with a conical reflector, and thus formed, if the expression may be allowed, a thermal telescope, with which the heat of a cloud of the

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apparent size of the moon was readily perceptible.* When this instrument was directed first to the clear sky in the vicinity of a cloud, and then immediately after to the cloud itself, the needle of the galvanometer attached to the thermo-electric pile in the tube always deviated several degrees. At first sight it might appear from this experiment that the heat of the cloud was greater than that of the transparent air in which it was floating, but this was not necessarily the case; the rays of heat from the apparatus when it was directed into the clear sky passed off into celestial space, while when the instrument was directed to the cloud they were absorbed and radiated back. It is probable however that the lower surface of the cloud is really a little warmer than the air in which it is floating, from the radiation of heat by the earth, while the upper surface is probably colder on account of the uncompensated radiation into space. But be this as it may, the counter radiation of the clouds prevents the sufficient cooling down of the bodies at the surface of the earth for the deposition of dew, or at least for the formation of a copious quantity. A haziness of the atmosphere (and it is probable a large amount of invisible vapor) will retard the radiation, and hence a still, cloudless night, without a deposition of dew, is considered as indicative of rain. The amount of deposition of dew will also depend upon the stillness of the atmosphere; for if a brisk wind be blowing, the different strata of air will be mingled together, and that which rests upon the surface of the ground will be so quickly displaced as not to have time to cool down sufficiently to produce the deposition.

Again the deposition will be more copious on bodies the surfaces of which are most cooled by the radiation. It is well known that different substances have different radiating powers. The following table from Becquerel exhibits the proportional tendency of different substances to promote the deposition of dew. The figures do not represent the relative emisssive power, but the combined effects of emission and conduction:

*[See *ante*, vol. I, p. 283.]

1.	Lamp black	100
2.	Grasses	103
3.	Silicious sand	103
4.	Leaves of the elm and poplar	101
5.	Poplar sawdust	99
6.	Varnish	97
7.	Glass	93
8.	Vegetable earth	92

Polished metals are of all substances the worst radiators; they reflect the rays of heat as they do those of light, and it would appear that the escape of heat from the substance of the metal is prevented by internal reflection. In order that the surface of a body should cool down to the lowest degree it is necessary that it should be a good radiator and a bad conductor, particularly if it be in a large mass and un-insulated. Thus the surface of a mass of metal coated with lamp black, though it radiates heat freely, will not be as much cooled under a clear sky as a surface of glass, since the heat lost at the surface is almost immediately supplied by conduction from within. If however a very small quantity of metal such as gold leaf be suspended by fine threads, the dew will be deposited, because the heat which is radiated is not supplied by conduction from any other source, and hence the temperature will sink to a low degree.

M. Melloni has within a few years past repeated the experiment of Wells, and established the correctness of his conclusions; and has also added some particulars of interest. He found that the apparent temperature of the grass, which in some cases was 8°or 10° lower than that of the air at the height of 3 or 4 feet, was not entirely due to the actual cooling of the air to that degree, but to the radiation and cooling of the thermometer itself, the glass bulb of which is a powerful radiator. To obviate this source of error in estimating the temperature he placed the bulbs of his thermometer in a small conical envelope of polished metal of about the size of an ordinary sewing thimble. This prevented a radiation and by contact with the air indicated its true temperature. He found with thermometers thus guarded that the solid body was in no case cooled down more than 2° below the temper-

ature of the surrounding air, and that the amount of radiation was nearly the same at all temperatures. The explanation therefore of the great cold of the air between the blades of grass is as follows: By the radiation of the heat the grass is at first cooled two degrees lower than the air at the surface of the earth, and next the thin stratum of air which immediately surrounds the grass is cooled by contact to the same degree. It then sinks down and another portion of air comes in contact with the blade of grass, and is in its turn cooled to the same extent, and so on until all the air between the blades is two degrees lower than that of the air farther up. The radiation however continues, and a stratum of air from the mass already cooled is cooled two degrees more, which sinks down as before, and so on until the air between the blades is cooled to 4° below its normal condition; and in this way the process may be continued until the temperature descends to 8° or 10° below that of the stratum of air a few feet above. In this way we can readily explain the small amount of dew deposited on the tops of trees, since the air as soon as it is cooled sinks down toward the ground, and its place is continuously supplied by new portions of the atmosphere. To the same cause we may attribute copious deposition of dew on wool and other fibrous materials which, though they do not radiate heat more freely into space, yet entangle and retain the air between their fibres, and thus allow the cooling process we have described to go on. It would appear that spider-webs radiate heat freely into space, since they are generally covered with a large amount of dew; their insulated position prevents them from renewing their heat, but according to the above principle a much larger amount of deposition ought to be produced by the same material were it loosely gathered up into a fibrous mass. The fact of the screening influence of the clouds teaches us that a thin cloth or even a slight gauze supported horizontally over tender plants is sufficient to neutralize the radiation and to prevent injury from frost during the clear nights of spring or autumn. The same effect is produced by artificial clouds of smoke.

Since radiation from the surface of the earth is most intense on clear nights, when the moon is visible, many of the effects which are due to this cause have been referred to lunar influence; for example, a piece of fresh meat exposed to the moonlight is said to become tainted in a few hours; this may arise from the deposition of moisture on the surface of the meat due to the cooling from radiation. The moon itself however acts as a cloud and radiates back to the earth a portion of the heat which it received from the earth as well as a portion of that which it received from the sun; and hence Sir John Herschel has referred to this cause, with apparent probability, the origin of an assertion of the sailors that "the moon eats up the clouds." He supposes that they may be dissipated by the radiant heat from that body, which being of low intensity and but feebly penetrating the lower stratum of the atmosphere may serve to dissipate the clouds. Though a wrong explanation is generally given by the popular observer of natural phenomena, and though effects and causes are frequently made to change places in his explanations, yet it is true, as Biot has properly said, that the scientist who devotes himself assiduously to investigate the subject of popular errors will find in them a sufficient amount of truth to fully repay him for his labor.

Formation of fogs.—The difference between a fog and a cloud relates principally to the conditions under which they are severally formed. A fog has been aptly called a cloud resting on the earth and a cloud a fog suspended in the atmosphere. The circumstances under which a fog is usually produced are the following: Either the surface of the earth or water is warmer than the air or it is cooler. If the temperature of a river or of a damp portion of ground is higher than that of the atmosphere which rests upon it the warmer surface will give off vapor of an elastic force due to its temperature. Should the superincumbent air be extremely dry the vapor will diffuse itself up through it in an invisible form without condensation, and no fog will be formed until by the continuation of the process the air becomes completely saturated; and then if an excess of heat remain in the evapo-

rating surface the fog will be produced, and will increase in density and height so long as a difference of temperature continues. If however a wind be blowing at the time, so that successive portions of unsaturated air are brought over the place, no fog will be produced. A still atmosphere therefore is a necessary condition to the accumulation of fog.

The foregoing is the usual method in which fog is produced, for it is well known that in cold weather the surfaces of lakes and rivers are much warmer than the stratum of air which rests upon them.

It is however frequently observed that fogs are formed during still nights in low places when the surface of the ground is colder than the stratum of the atmosphere which rests upon it, and indeed we have shown that the temperature of the surface of the earth on a still and clear night is always lower than that of the air which is immediately in contact with it; and it is not easy, without further explanation, to see the reason why fogs should not always be produced in this case as well as dew. When the atmosphere is still the condensation of the vapor by the coldness of the surface is so gradual that the air is not disturbed, and the stratum immediately above the grass has relatively less moisture in it than that a few yards higher; hence no fog ought to be produced in this case, since all the precipitation produced is that which has settled directly upon the grass in the form of dew. In this case we may define the dew to be a fog entirely condensed into drops of water. The question still arises how under these circumstances can a fog really be produced. The answer is that another condition is required, namely that the surface cooled by radiation should slope to a lower level, as in the side of a hill or the concave surface of the sides of a hollow. In this case the superincumbent stratum of air of which the temperature has been lowered by contact with the cold earth, flows down the declivity by its greater weight into the valley below, and there mingling with the damp air which generally exists in such places, precipitates a part of its transparent vapor into visible fog. In this manner large hollows are sometimes seen in the morn-

ing filled with a mass of fog, exhibiting a definite and level surface presenting the appearance of a lake the shores of which are the surrounding eminences; and if a depression of sufficient depth occurs in any part of the circumference of the basin, through this the fog is seen to flow like a river from the outlet of a lake.

The explanation we have here given of the formation of fog in low places is also applicable to the phenomenon frequently observed of early frost in the same localities. As rapidly as the air is cooled on the sides of sloping ground it sinks into the valley below and its place is supplied by the warmer air above, which has not been subjected to the cooling influence. In the vicinity of Washington the hollows are sometimes found several degrees colder than the more elevated parts of the surrounding surface. Fogs are produced on the ocean when a gentle wind charged with moisture mingles with another of a lower temperature. The wind from the Gulf Stream mixing with the cold air which rests upon the water from the arctic regions, (which as before stated flows along close to the eastern shores of our continent,) gives rise to the prevalence of fog over the Banks of Newfoundland.

There is another atmospherical phenomenon which though it does not affect the hygrometer and is only indirectly connected with moisture, is generally classed with fogs. I allude to what is called dry fog—a smoky haziness of the atmosphere, which frequently extends over a large portion of the earth. The nature of these fogs is now pretty well understood, and more refined observations, particularly with the microscope, have served to dissipate the mystery in which they were formerly enshrouded. When a portion of the air in which the fog exists is filtered through water and the substance which is retained is examined by the microscope it is found to consist of minute fragments, in some cases of burnt plants, and in others of the ashes of volcanoes. It is surprising to what a distance the pollen of plants and minute fragments of charred leaves may be carried. Samples of substances which have been collected from rain water and ex-

amined microscopically by Professor G. C. Schæffer of Washington, at the request of the Smithsonian Institution, have been found to consist of portions of plants which must have come from a great distance, since the species to which they belong are not found in abundance in the localities at which the specimens were obtained. It is highly probable that a portion of the smoke or fog-cloud produced by the burning of one of our western prairies is carried entirely across the eastern portion of the continent to the ocean. On this subject Dr. Smallwood communicated a series of interesting observations to the American Association at their meeting in Albany in 1855. Particles of matter of the kind we have described are good absorbers and radiators of heat, and hence in the daytime they must become warmer than the surrounding atmosphere and tend to be buoyed up by the expansion of the air which exists in the interstices between them, while at night they become cooler by radiation than the surrounding air and tend to condense upon themselves the neighboring moisture, and consequently to sink to a lower level. It is on this account that the smoky clouds which are produced by the enterprising manufacturing establishments of Pittsburg and other western cities, sometimes descend in still weather to the surface of the earth and envelop the inhabitants in a sable curtain more indicative of material prosperity than of domestic comfort. From the density and the wide diffusion of these smoky clouds they must produce a sensible effect upon the temperature of the season of the year in which they occur. During a still night, when a cloud of this kind is over head, no dew is produced; the heat which is radiated from the earth is reflected, or absorbed and radiated back again, by the particles of soot, and thus the cooling of the earth necessary to produce the deposition of water in the form of dew and hoar frost is prevented.

So well aware of this fact are the inhabitants of some parts of Switzerland that, according to a paper by Boussingault, in a late number of the *Annales de Chimie*, they kindle large fires in the vicinity of their vine fields and cover them with brush to produce a smoke-cloud by which to defend the

tender plants from the effects of an untimely frost. Though the first announcement of the proposition by some of our earlier meteorologists that the peculiar condition of the atmosphere known as "Indian summer" might be produced by the burning of the prairies, was not thought deserving of any comment, yet the advance of science in revealing the facts just stated renders this hypothesis by no means unworthy of attention. A large amount of smoke existing in the atmosphere must have a very sensible effect in ameliorating the temperature of the season by preventing the cooling due to radiation; and although this may not be the sole cause of the peculiarity of the weather above mentioned, it may be an important consideration in accounting for the smoky appearance of the air and the effect produced upon the eyes.

In concluding this section we would commend to the attention of the microscopists of this country,—as a readily accessible and interesting field of research,—the subject of atmospheric dust. The atmosphere constantly holds in suspension a mass of particles derived from the mineral crust of the globe and from animals and vegetables, which by being deposited in undisturbed positions, serves as a record to be read by the microscope of changes alike interesting to the antiquarian and the naturalist. On this subject M. Pouchet has lately presented a paper to the French Academy of Science, in which he enumerates the particles of mineral, animal, and vegetable origin which he has found deposited from the atmosphere. Under the latter he mentions specially particles of wheat flour which have been found as an ingredient of dust in tombs and vaults of churches undisturbed for centuries. The dust floating in the atmosphere may readily be collected by filtering the air through a tube swelled in the middle, bent into the form of a syphon, partly filled with water and attached at the lower end to the vent-hole of a cask from which water is drawn, or simply by sucking through the air by means of the mouth.

Rain.—The discussion of the *rationale* of the production of rain will be given in a subsequent part of this article. We shall in this place however state some facts in regard to it

which are naturally connected with the general subject of the existence of vapor in the atmosphere.

The humidity so constantly supplied to the air by evaporation is returned to the surface of the earth principally in the form of rain resulting from the union of the very minute particles of water which constitute the mass of clouds. Without stopping to inquire into the cause of union in this place we may remark that we think it probably due to the further condensation of the vapor which first assumed the condition of a cloud. Rain, it is true, has been observed to fall from apparently a cloudless sky, but the occurrence is one of extreme rarity, and it seems possible that it is brought from a distance by wind at a high level.

A knowledge of the quantity of rain which falls in different portions of a country is important, not only with reference to agriculture, but also with reference to internal navigation, as well as to the application of hydraulic power, the occurrence of devastating floods, the water supply of cities, and the sanitary condition of a district.

Almost every portion of the earth on which rain falls is provided with natural drains that carry off the surplus water (above that which evaporates) to the ocean whence it came; and taking the earth as a whole the same amount of water must be returned to the ocean as was taken from it by evaporation.

Nearly the whole surface of the earth is divided into basins, each provided with a separate system of drainage. The boundaries of these basins can readily be traced on the map by drawing a line around between the heads of the streams, the waters of which find the level of the ocean through the channels of different rivers. Thus we have the great primary basins of the Amazon, the Mississippi, and the St. Lawrence, and the secondary basins of the Ohio, the Missouri, and the Tennessee, giving the latter name to those which pour their waters not into the ocean but into another river.

A knowledge of the amount of rain which falls on each of the subordinate basins supplying a river like the Mississippi

with the water which passes through it into the ocean, if transmitted by means of the telegraph, would be of the greatest value, in connection with previous experience as to the elevation of the water of the river corresponding to a given indication of the rain-gauge, in furnishing the means by which the effects of floods may be guarded against and the labors of the husbandman along the banks preserved, in many cases, from destruction. A single gauge in each subordinate basin would be sufficient to furnish valuable practical information of this kind, and in the case of the Mississippi River, (especially if applied to the basins on the eastern side,) would suffice to give premonitory indications of a sudden rise at the lower part of the river, since the water which is furnished from the western part of the valley of the Mississippi is more constant in its amount, or in other words not so subject to fitful variations.

The simplest method of measuring the rain, which any one may practice for himself, is to catch the water in a cylindrical vessel, like an ordinary tin pail, and to measure the depth in inches and tenths of an inch after each shower. It is hardly necessary to remark that the vessel should be so placed that it may not be screened by trees, buildings, and other obstacles from the wind which bears along the falling drops. The object of the investigation is to ascertain the number of inches of water which fall from the clouds on a given space in a given time—for example, a year or a season. It is well known that while the wind is blowing strongly the drops descend in an oblique direction, and gauges have been proposed which, by the action of the wind, would so incline their mouths as always to present them at right angles to the direction of the drops; but gauges of this kind would not give the indication required, which is that of the absolute quantity of rain which falls on a given horizontal extent of the surface of the earth.

A remarkable fact has been observed as to the amount of rain collected at different heights. It is a well known phenomenon, of which we shall give the explanation hereafter, that on the windward side of a mountain a greater amount

of rain falls annually than at a less height on an extended plain. The effect however, to which we now refer, is just the reverse, since it is found that less rain falls on the top of a tower, and even of an ordinary building, than at the bottom. This phenomenon is due in part at least to the fact that a drop in its descent through a foggy atmosphere, in which the rain is falling, catches in its path all the minute particles of water between the upper and lower stations. It cannot be due, except in a slight degree, to the condensation of the transparent vapor in the atmosphere which occupies the line of its descent, since the condensation of this would rapidly heat the drop of water, although its temperature were considerably lower than that of the air, on account of falling from a colder region. The principal cause of the difference is to be found in the effect of the wind in passing over and around the edifice on which the gauge is placed. The effect of this cause was first investigated by Professor Bache, of the United States Coast Survey, who made a series of observations with a number of gauges placed on different sides of the roof of a shot tower in Philadelphia. He found that different quantities of rain were collected by gauges thus placed.

To explain the effect of the wind, we may refer to what takes place when an obstacle like that of a large stone is found with its upper end just below the surface of a running stream. The water of the current will pass over and around the stone, and will rise above the general surface; there will exist a tendency to a partial vacuum on the sheltered side; the liquid in passing over and around the stone will be accelerated; the particles of water which pass around the stone, supposing it to be a cylinder, will traverse a space equal to the semi-circumference of the circle, while those moving along the general current, and not deflected, will pass through a space equal to the diameter of the same circle. A similar effect would be produced by the wind striking against a tower. The portion which passes around the top will be accelerated; that which strikes against the top will be deflected upward, and in both cases a diminution in the quantity of rain which falls on the top of the tower will be the result.

Suppose the wind is coming from the west, and striking with force against the side of the tower which faces that direction, it will be deflected upward, and thus retard the fall of rain on the near side of the roof of the tower, and precipitate it over the leeward side, while the portion of wind which passes around the circumference of the tower, near its top, will be accelerated, and will by the latter action impart its motion to the air on the north and south sides of the roof of the tower, which will cause the drops of rain to be crowded together on the leeward side.

The effect of the upward deflection of the wind and the acceleration of the rain, under conditions such as we have just described, are strikingly illustrated by the observations which were made on the high tower of the Smithsonian Institution. Three gauges were placed on the roof of this tower,—one on the west, one in the centre, and a third on the east side. Now if the prevailing wind be west, we should expect (if the theory which we have presented is correct,) that the west gauge would contain the smallest quantity of water, the middle one next, and the one on the east side the greatest; and this was found to be actually the case.

The action of the wind also materially affects the amount of water which falls in different gauges of different forms and sizes at the surface of the earth. It is well known that different gauges, which indicate the same amount of rain in calm weather, differ materially in the quantity of water which they collect in high winds. If the gauge be of considerable size, and project above the surface of the earth, the air will be deflected upward and accelerated around it, as in the case of the tower; nor is this result obviated by sinking the large gauge to the level of the earth, since in that case the current curves down into the gauge and tends to carry out a portion of the falling drops on the opposite side. From a series of experiments made at the Smithsonian Institution, and continued for several years, it is found that a small cylindrical gauge, of 2 inches in diameter, and about 6 inches in length, connected with a tube of half the diameter, to retain and measure the water, gives the most accurate results.

In still weather it indicates the same amount of water as the larger gauges, but when the wind is high it receives more rain, for on account of its small size the force of the eddy which is produced is much less in proportion to the momentum of the drops of water. This gauge, which has been copied from one introduced by Mr. James Stratton, of Aberdeen, may be still further improved by cutting a hole of the size of the cylinder into a circular plate of tin of 4 or 5 inches in diameter, and soldering this to the cylinder like the rim of an inverted hat, three or four inches below the orifice of the gauge.

The effect of the wind in disturbing the level of light snow in the vicinity of buildings illustrates the general principles which we have endeavored to explain. When a rapid current of air is obstructed by a building the acceleration of its velocity on the side of the eddy is marked by the removal of the snow to a considerable distance. Indeed all the phenomena we have mentioned in regard to rain are illustrated by the extraneous motion given to the particles of descending snow.

Constitution and phenomena of the compound atmosphere.—From the principles we have endeavored to explain, we may now readily infer what would be the general effects if the earth were surrounded with an ocean of water and devoid of an atmosphere. At first sight it might appear that all the water of the ocean would immediately pass into vapor; but, on a little reflection, it will be seen that this would not be the case. A definite amount of vapor would be formed, which by its pressure on the surface of the water would prevent any further evaporation, provided the whole globe and the space around it were of uniform and constant temperature.

A portion of vapor would rise from the water and would expand as it rose until the upper atoms were so far separated that their repulsion would become insensible and they would be retained as an appendage to the earth merely by their weight. The upper layer of vapor would press on the next lower, and this on the next, and so on with accumulating

weight as we descend; the aqueous atmosphere surrounding the whole earth would thus be found increasing in density as we approach toward the liquid surface. If the temperature of the earth and of the space around it were 60° F. it will be seen by table *A*, (p. 217,) that the pressure of this aqueous atmosphere at the surface of the earth would be equal to half an inch of mercury; if the temperature were 100° it would be equal to 2 inches. This pressure however would be sufficient to prevent any further evaporation, unless, as we have said, an increase of temperature took place.

In order that such an atmosphere should be in equilibrium it would be necessary that the absolute amount of heat in equal weights and at different heights should be the same; or in other words it should follow the same law as that of a gaseous atmosphere. There would however be this great difference between the two atmospheres, the one would be readily condensed by a diminution of temperature beyond a certain point into water, while the other would remain a permanently elastic fluid at all temperatures. If therefore the space beyond the atmosphere were colder than that which would be due to the diminution which would naturally take place in an aqueous atmosphere, a continual rain would be the result, the moisture would be constantly evaporated from the surface of the earth, and constantly condensed by the cold above. Now were it not for the gaseous atmosphere which surrounds the earth and offers a resistance to the ascent of the aqueous particles, we think such a condition would actually exist. We are inclined to this belief from the facts which have been stated indicating an exceedingly low temperature to the space beyond our atmosphere.

Be this as it may however, an atmosphere of this kind would be exceedingly unstable, and if any portion of the earth's surface were colder than another there would be a constant condensation at the coldest parts, and a constant evaporation at the warmest to restore the equilibrium. If for example the heat of the equatorial regions were 80°, and that of the polar regions at zero, the elastic force of the vapor at the former place would be 1 inch, while at the latter it

would be but 0·043 of an inch; hence an equilibrium could not exist, and there would be a continued series of currents from the equator to the poles, a perpetual condensation of vapor into water at the latter, and a constant evaporation of liquid into vapor at the former, for the supply of which a series of ocean currents would be established. A tendency to the same effect must exist in the compound atmosphere of air and vapor which actually surrounds our earth, but the resistance to the permeation of the vapor is so great that a considerable inequality of the elastic force of vapor continually exists in different parts of the earth.

Though there is a constant tendency to a diffusion of vapor from the equator to the poles, yet the greatest disturbance of the equilibrium of our atmosphere results from the diminution of temperature as we ascend in the atmosphere, and for the establishment of the principle on which this disturbance depends, and the consequences which flow from it, we are indebted to the laborious, persevering, and sagacious investigations of Mr. James P. Espy.

From observation it is well known that the air diminishes in temperature as we ascend, at the rate of about one degree Fahrenheit for each 100 yards or 300 feet. If therefore a portion of air be transferred from the surface of the earth to a height in the atmosphere, it will be cooled to the temperature of the stratum of air at which it arrives; but it is proper to observe at the beginning of the explanation that this cooling will not be due principally to the coldness of the space to which the mass of air has been elevated, but chiefly to its own expansion. If the air for example expands into double the space by being subjected to half the pressure, it is evident that the amount of heat which it contains will be diffused through twice the amount of space; and hence though the absolute quantity of heat remains the same, its intensity of action, or its temperature, will diminish and the substance will become much colder. This is a principle to which we have before alluded, and which will be frequently applied hereafter in the explanation of phenomena.

If in accordance with the foregoing an upward motion takes place from any cause whatever in a mass of air saturated with vapor, a precipitation must instantly follow. For example, if we suppose the moist air to be raised to the height of 1,000 yards, and if we further suppose the temperature at the surface to be 70° the temperature at the height of 1,000 yards will be 60°; and if we inspect table *B* (page 225), at these numbers, we shall find opposite 70° 7·99 grains of vapor for each cubic foot; and opposite 60°, 5·75 grains of vapor for each cubic foot. In this case therefore nearly 2·24 grains of vapor will be converted into water and fall as rain. We see from this simple consideration that the mere upward motion of a portion of saturated air, from whatever cause produced, must give rise to a precipitation of vapor in the form of water. It may not be in sufficient quantity to come to the earth in the form of rain, but may remain in the air in the intermediate state of a fog or a cloud.

If the air be not saturated entirely with vapor no precipitation will ensue until it rise to the height at which it becomes by the diminution of temperature fully saturated. Suppose for example the air at the surface is 70°, and the vapor in it is that due to 65°; then it is plain that it must be reduced in temperature 5° before precipitation commences, and this reduction will take place at the height of 500 yards, since, as we have just stated, the reduction of temperature is one degree for each 100 yards of ascent. And by this simple method Mr. Espy has shown that we may, on a given day, approximately estimate the height of the base of a cloud by merely knowing the dew point at the surface of the earth; for if we find that while the temperature of the air is 70°, there is required at the same time to produce a deposition of dew on the exterior surface of a tumbler, a reduction of temperature of 6° (for example) of the water within, the cloud would be 600 yards above the surface of the earth, because it will be necessary that the vapor should rise to that height in order that the whole mass may be cooled to the point of deposition. The bottom of this cloud will be horizontal,

because the precipitation begins at a definite temperature due to a definite height; its form will be that of a mushroom, bulging out and gradually increasing in altitude; in short, will be precisely that form of cloud which is denominated cumulus, and which may be seen during a moist warm day forming in a still atmosphere, gradually extending upward until the precipitation of vapor begins to be so copious that the particles of water coalesce and form drops of rain, which falling down directly through the base of the cloud, leave but a remnant of very attenuated vapor, which is blown away and forms, according to Mr. Espy, the cirrus or hair clouds.

We can also readily infer from the same principle that so long as a current of air moves horizontally over a plain of uniform temperature, no precipitation will take place; but if in its course it meets with a mountain, up the acclivity of which it will be obliged to ascend and thus come under a less pressure and lower temperature, a precipitation must ensue. We have in this way a natural explanation of the effect of a mountain in causing a cloud and a fall of rain, and need not refer the phenomena to the unscientific explanation of attraction so frequently given; we say unscientific, because the attraction of gravitation at a distance on an atom of vapor, is almost infinitely small, and could have no appreciable effect in drawing the clouds. If we suppose, in addition to the preceding case, that the air, after ascending to the top of the mountain and forming a cloud by the precipitation of its moisture, descends on the other side to the same level, it will arrive at the earth much dryer than it went up. If the height of the mountain is not sufficient to reduce the temperature enough to produce a rain, but merely a cloud, and if we suppose the current of air to continue its course, and to descend to the same level on the other side, it will, as it descends, become condensed as it comes under greater pressure; the temperature will increase for a like reason to that which caused its diminution in the ascent.

We have in this way an explanation of the paradoxical appearance of a strong wind blowing across the top of a

mountain, while a light cloud, which crowns its summit and perhaps hangs over its sides, remains apparently immovable. The truth is that this cloud, which appears stationary, is in reality a succession of clouds constantly forming and constantly dissolving. Every portion of air which ascends the mountain, tends (by its expansion and cooling) to form a new portion of cloud, and in its descent tends (by its condensation and increase of temperature) to dissolve a similar portion. The cloud is consequently forming on one side and dissolving on the other, and in this condition may aptly represent the dynamical equilibrium of the human body; which, by every expiration of breath is wasting away, and by every pulse of the heart is renewed.

What we have given may be considered as the more obvious inferences from the first and simplest propositions of Mr. Espy's theory. The phenomena as they occur in nature however are more complex, and another effect is produced by the upward motion of the air, which very essentially modifies the results; we allude to the great amount of heat which is evolved during the condensation of vapor into water. We have stated that the heat evolved from the combustion of 20 pounds of dry pine wood is absorbed by a cubic foot of water at the ordinary temperature of the air in its conversion into vapor, and it is evident that this vapor cannot be re-converted into water without giving out to the surrounding bodies an amount of heat equal to the combustion of 20 pounds of dry wood.

In order to give an idea of the importance of this principle, which is an essential element in the theory of Mr. Espy, it will be necessary to dwell somewhat longer on other points before considering more minutely the results to which it leads.

Statical equilibrium of the compound atmosphere.—Before proceeding to discuss the subject further, it will be necessary to consider the question, which appears to be in a very unsettled state, as to the effect of vapor in the atmosphere while in the act of diffusion. On the one hand, the resistance which air offers to the diffusion of vapor has bee[illegible] 1

disregarded, and on the other, we think too much effect has been attributed to this cause. It is customary in reducing the observations made at European observatories to deduct the elastic force of the vapor in the atmosphere at a given time from the height of the barometer, and to consider the remainder as the pressure of the dry air. This process would give a correct estimate of the pressure of the dry air, provided the gaseous envelope of the earth were a perfect vacuum to the vapor, and the latter were consequently regularly diffused through the space in accordance with its diminution of density due to a diminution of pressure and temperature as we ascend; but this we know to be far from the fact. In the balloon ascent of Mr. Welsh, on the 21st of October, 1852, the tension of vapor at the elevation of 800 feet was observed to be greater than at the ground, and at a height of 3,000 feet it was still greater. In an ascent of the same observer on the 17th of the previous August, the tension continued to increase until an elevation of 8,400 feet was reached.

To render this point more clear, we will for a moment consider the relation of tension and pressure. By the tension of vapor, (as has been seen,) we understand the elastic force or repulsion of the atoms combined with the action of heat by which they tend to enlarge the space in which they are enclosed, and to force down the mercurial column in the experiments by which table *A* (p. 217,) was constructed. At the temperature of 60° F. this elastic force is just balanced by a column of half an inch of mercury. Let us now consider the nature of tension in regard to the atmosphere; for this purpose let us suppose a piece of paper pasted over the mouth of a glass tumbler so as to be air tight. This paper, though of a very fragile texture, is not broken in by the superincumbent pressure of a column of air extending to the top of the atmosphere and pressing with a force equal to nearly 15 pounds on every square inch of the surface of the paper, because it is counteracted on the lower surface by an upward pressure due to the repulsive action or elastic force, that is to the tension of the inclosed air. The weight of the superincumbent column on the upper side of the paper is known as the weight

or pressure of the atmosphere, while the upward pressure on the lower side, due to the repulsion of the atoms, is designated indiscriminately by the terms *elasticity*, *elastic pressure*, *elastic force*, and simply the *tension* of the air.

The force analogous to the latter (in the case of vapor) is more generally known by the name of *tension*, though it is sometimes called *elastic pressure*. In the foregoing experiment, if the pressure of the superincumbent air is increased, the exterior surface of the paper will assume a concave form, the atoms of the inclosed air will be pressed nearer together, and their repulsive energy will be increased by the approximation of the atoms, and thus a new equilibrium will take place. If conversely the column of air above the tumbler is diminished in weight, the surface of the paper will assume a convex form, because the atoms within the tumbler being pressed with less force will separate to a greater distance, and the repulsion will be reduced by their separation, until a new equilibrium is attained between the pressure without and the repulsion within. In this case, variations of the elastic force or tension of the air within the tumbler become an exact measure of the pressure of the exterior column, provided the temperature remains the same; and it is upon this principle that the barometer called aneroid is constructed. It consists practically of a flat flask of thin metal, filled with air and hermetically sealed by means of solder; the motion of the sides of this flask, precisely analogous to that of the paper closing the mouth of the tumbler, is communicated by means of lever and wheel work to a hand, which indicates the variations of the tension of the inclosed air and consequently of the weight of the atmosphere.

Now if the aqueous vapor formed a separate or entirely independent atmosphere around the earth, the variations in its pressure would be accurately measured by the variation of its tension or elastic pressure at the surface; but since the vapor, on account of the resistance of the air with which it is entangled, is not uniformly distributed, its tension at the surface cannot give a true measure of its whole pressure. It is true that as a whole the weight of the atmosphere is in-

creased by the addition of every grain of water which rises in the form of vapor from the surface of the earth or ocean, but when the evaporation is copious in a limited space, as for example, over the surface of a pond of water, or a portion of the earth subject to sunshine while the regions around are obscured by clouds, the elastic force of the vapor tends to diminish the specific gravity of the aerial column and to produce a fall rather than a rise of the barometer. This is always the case while the vapor is in the act of diffusion; for the resistance of the atmosphere at the surface of the expanded volume of vapor may be considered as an elastic envelope against which, as in the case of the India-rubber bag to which we have previously alluded, the aqueous atoms press by their repulsion and tend to expand it, and therefore to increase their own volume as well as that of the inclosed atmosphere.

If the vapor ascended into the air without resistance, (as in a vacuum,) it would in all cases increase the weight of the latter, but on account of the resistance under the conditions we have just mentioned, the ascending vapor by its elasticity would lift up the atmosphere, tend to lessen its pressure, and thus temporarily to expand the air in the space included within the surface of the aqueous volume. It is therefore a difficult point to ascertain in the explanation of these phenomena, when we must consider the weight of the atmosphere increased, or when diminished—by the pressure of vapor.

It is evident from the experiments which have been made on evaporation under diminution of pressure of air, that the resistance to diffusion spoken of diminishes in proportion to the rarity of the atmosphere; and hence the vapor which exists at great elevations would be in a state of entire diffusion, and its presence would increase the specific gravity of a portion of air through which it is disseminated, instead of diminishing it.

We think erroneous conclusions have frequently been arrived at on account of a want of a proper consideration of this subject, and from too exclusive an attention to the expansive influence of the aqueous vapor in a confined space

on the one hand, and the increased pressure of the whole atmosphere by the addition of vapor on the other.

It is probable however that in portions of the earth in which the air is constantly saturated at a uniform temperature and at which the diffusion is permanently uniform, if the elastic force of the vapor is subtracted from the whole height of the mercurial column it will give the pressure of an atmosphere of dry air.

On the supposition that the vapor is uniformly distributed through the atmosphere, (which will not be far from the truth if considered with reference to the principal zones of the earth,) we can calculate the whole weight of water contained. If the water were at the boiling point its elastic tension or pressure would be equal to the pressure of the atmosphere, and in this case it would support 30 inches of mercury, or its equivalent, 407·4 inches of water; and since transparent vapor observes the same law of expansion and contraction by variations of pressure and temperature that dry air does, it is clear that we shall have the following relation for any other temperature, namely, as 30 inches is to the quantity of mercury expressing the elasticity of the air at any temperature, so is 407·4 inches of water to the whole weight of the aqueous vapor, provided the weight of vapor were the same as that of the air. It has however been proved by the experiments we have described that vapor is only five-eighths of the density of air, and therefore the quantity found by the foregoing relation must be reduced in this ratio.

If we assume that the dew-point is on an average 6° below the temperature of the air, and allowing the temperature of the tropical regions to be 82°, we shall have the following proportion,—30 : 0·897 : : 407·4 : 12·181. This last number must however be multiplied by $\frac{5}{8}$, and this will give us 7·613 inches. From this it will appear that if the atmospheric columns at the equator were to discharge their whole watery store the moisture precipitated would cover the earth to the small depth of 7·613 inches; and from a similar calculation we find that if the column of air resting upon the city of

Washington were to precipitate at once all its moisture, the quantity of water would be indicated by about 3 inches of the gauge. To supply therefore 30 or 40 inches of rain in the course of a year it is necessary that the vapor contained in the atmosphere should be very frequently renewed, and that consequently localities which cannot be reached by moist winds must be abnormally dry.

Effects of vapor on the general currents of the atmosphere.— From what has been previously stated it is evident that the atmosphere which surrounds the globe being composed of two portions, one of permanent elastic gases, and the other of a readily condensable vapor containing a large amount of latent heat, it must frequently be in a state of tottering equilibrium, liable to be overturned by the slightest extraneous forces, and in assuming a more permanent condition to give rise to violent commotions, and currents of destructive energy.

It has previously been shown that the equilibrium of a dry atmosphere depends upon the fact that each pound from the top to the bottom of an aerial column contains approximately the same amount of heat. If therefore a portion of air be caused to ascend (by mechanical or other means) to a greater elevation, it will expand, and its heat being distributed through a larger space, its temperature will fall to that of the new region to which it has been elevated, and be again in equilibrium. If on the other hand a portion of air be caused to descend, it will be condensed into a smaller space on account of the increased pressure, and its temperature will be raised to that of the stratum at which it has arrived. But this is not the case with moist air; for if by any means it be elevated above a given level, the coldness produced by its expansion will, as we have said, condense a portion of the vapor into water, and in this process the vapor will give out its latent heat to the surrounding air, and therefore the column in which this condensation has taken place will not be as cold as the surrounding atmosphere; consequently an upward force will still exist, the column will rise to a greater height, and a new portion of vapor

will be formed, and so on until all or nearly all the vapor will be converted into water. In this way the steam power, which has been accumulated from the heat of the sun, is expended in producing commotions of the atmosphere connected with all the fitful—and many of the regular—meteorological phenomena of the globe.

It may be objected to this part of the theory of Mr. Espy that the condensation of the vapor in the atmosphere would tend to contract it into a smaller space, consequently to render it heavier, and thus neutralize the effect of the expansion due to the evolution of the latent heat. The effect however from this cause is very small in comparison to that due to the expansion of heat; and this will be plain when we consider that the particles of vapor exist in the interstices of the particles of air, and in a close vessel tend to increase the volume only in proportion to their repulsive force, which compared with that of the air, is small. For example, if a quantity of dry air were inclosed in an India-rubber bag, at a temperature of 60°, at the level of the sea, its elastic pressure outward on the sides of the bag would be equal to the weight of 30 inches of mercury, while the elastic force of vapor would only be equal to half an inch of mercury; so that we should have the enlargement of the bag expressed by the last term of the following proportion: If 30 inches of mercury give one foot what will 30·5 give? In this case, which is an extreme one, we see it would give but a little more than 1 per cent., and hence the diminution due to extracting the vapor from a quantity of air is very small, and far less than the expansion due to the evolution of heat. This will be evident from the following calculation of the effect produced by the condensation of a pound of vapor into water: It is known from direct experiment that the condensation of one pound of vapor will raise 970 pounds of water 1°, or if it were possible to heat water thus high it would raise one pound of water 970°; but the capacity of air for heat is only one-fourth that of water; therefore the condensation of one pound of steam would raise one pound of air 3,880°, or 10 pounds of air 388°. The above calcula-

tion is from Daniell's Chemical Philosophy, and is given as an illustration of the immense motive power due to the fall of a single pound of water in the form of rain. During a single rain, in 1857, water fell to the depth of 6 inches in the space of 36 hours, and considering merely the amount of ascensional power evolved by the condensation of the quantity of the liquid which fell on the roof of the Smithsonian building, it would be equivalent to a thousand horse-power exerted during one day.

From these considerations it is evident that the general currents of the atmosphere must be very much modified by the action of the vapor, and very different from those described in our previous essays as belonging to dry air. Indeed to such an extent are some of the general phenomena influenced by this cause, that the motive power of the atmosphere has been referred to other causes than the action of the heat of the sun; but in this case, as in most other exceptions to a principle deduced from a wide generalization—like that of the action of solar heat on our atmosphere, the facts when rightly understood and properly interpreted, serve but more firmly to establish the truth.

We shall now consider more minutely the effect of the formation and condensation of vapor in modifying the general circulation of the atmosphere. It has been shown in the previous articles, that if the earth were at rest in space, without revolution on its axis, heated at the equator and gradually cooled to a minimum point toward the poles, there would be a constant circulation of air from the poles, north and south, toward the equator. The air would rise in a belt encircling the whole earth, and flow backward towards the poles above. In this simple circulation, at every place on the surface of the earth, in the northern hemisphere for example, there would be a perpetual wind from the north flowing toward the equator, and above the same place at the surface of the aerial ocean there would be a return current constantly flowing from the equator toward the pole. It is evident however since the meridians converge and meet at the pole, that the space between any

comes less and less as we depart from the equator; hence all the air which ascends at the equator could not flow entirely to the pole, but the larger portion of it would descend to the earth to return again to the equator, along the surface at some intermediate point, which would be, on an average, about the latitude of 30°, since the space included between this and the equator would be nearly equal to the remaining surface in each hemisphere. Again as we have seen, the simplicity of this system of winds would be interfered with by the rotation of the earth on its axis. On account of this rotation, as a general rule, when a current moves from the equator, in the northern hemisphere, for example, it would gradually curve to the east, and when it moves southward in the same hemisphere, it would curve to the west; the rapidity of curving in either case would increase as we approach the pole. On account of this curvature and deflection east and west of the upper and lower currents, together with the disturbance produced by the evolution of the latent heat, the simple system we first described will tend to separate, as we shall more fully see hereafter, into three distinct systems, which we have represented by A, B, and C, in the annexed figure.

Fig. 5 is a diagram intended to represent an ideal section

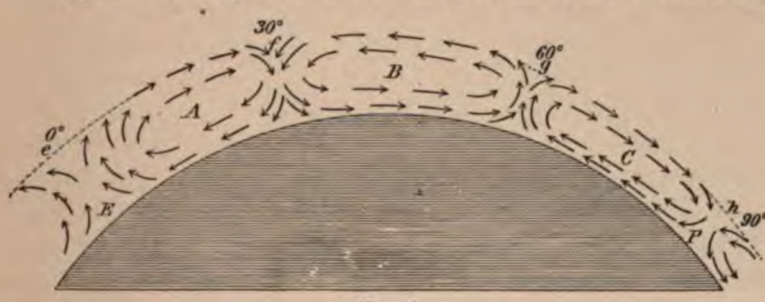

FIG. 5.

through a meridian of the northern hemisphere, showing the several systems of aerial circulation, commencing on the left at E (the equator), and completing the series on the right at P,—the north pole. Fig. 6 is a bird's eye view of the globe, designed to illustrate the prevailing direction of the

surface currents, particularly in the northern hemisphere. By comparing the two figures, it will be seen that the systems *A*, *B*, and *C*, of Fig. 5, correspond with the three zones of arrows in Fig. 6. To supply the air which ascends in the region near the equator, the current on each side, on account

Surface Winds of the Globe.

Fig. 6.

of the rotation of the earth, takes an oblique direction, (as we have seen,) flowing in the northern hemisphere from the northeast, and in the southern from the southeast. It continues its westerly motion as it ascends until it reaches its culminating point, and then flows backward in an opposite direction curving as it goes, toward the east.

The surface currents on either side of the equatorial region, (called the trade winds,) as they pass over the ocean constantly imbibe moisture, and deposit but little in the form of rain, since there is no obstacle on the level surface of the water to produce an upward current and the consequent

diminution of temperature essential to the formation of rain. They therefore carry their moisture to the belt of confluence, where in the ascent of the air it is precipitated, evolves its latent heat, and develops its ascensional power. To render the ascent of these currents more plain Fig. 7, may be considered a transverse section across the equator at the belt of calms.

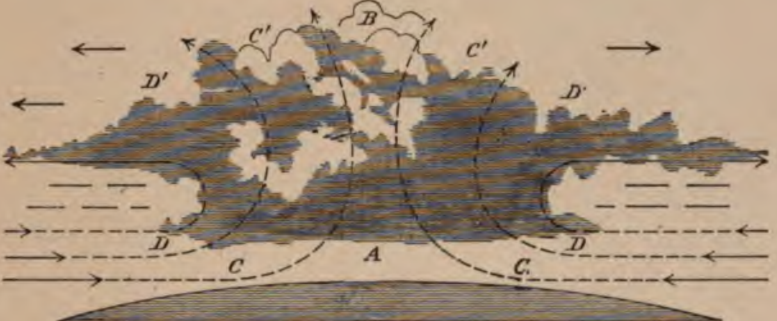

FIG. 7.

The air enters below on either side *D C*, rises upward in the middle space, and spreads out north and south above D′ C′. As the air ascends it comes under less pressure, expands, becomes colder, and on this account condenses a portion of its vapor, which renders the air warmer and lighter than it would be if this evolution of "latent heat" did not take place. Hence the ascension continues, and the elevation to which the column attains is therefore much greater than it would be if the air were void of moisture. The condensation of the vapor takes place in the form of a large amount of rain which falls by its superior weight through the ascending air, *A*, *B*, and deluges the surface immediately below, in some places to such an extent that fresh water on the surface of the ocean has been found floating on the top of the salt water. Indeed more rain falls on the surface within this belt than on the whole earth beside. On either side of the rain belt a cloud will be formed by the spreading out of the ascending air mixed with vapor, as shown in the figure. The falling rain coming from a high elevation and

having consequently a low temperature, will cool the surface of the earth below that of the spaces on either side.

The pressure of the air in the ascending column will be less than that on the regions north and south, since a portion of its weight is thrown over on either side. This fundamental principle, which has been strangely mis-understood, will be rendered evident by the annexed figure 8, in which A, B represents the surface of the earth, and a, b, and c, d, (the several parallel lines above,) the surfaces of the strata in which the air is supposed, for illustration, to be divided. The depth of these strata will be throughout the whole column increased, and the surface of the upper one will be elevated above the general surface of the atmosphere. Being unsupported, it will tend to flow over on the strata on each side; the surface of the next stratum below will also press outward with more force than it is pressed inward, and will consequently mingle with the air on each side, while the heavy air on each side below opposed by lighter air will press under the lower stratum and tend to elevate it. Between the bottom and the top there will be a neutral surface, marked o, which is in equilibrium.

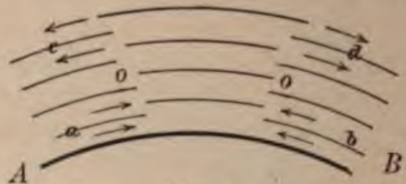

FIG. 8.

In the middle space at the bottom of the ascending column (Fig. 7), the air will be nearly at rest, subject however to fitful squalls due to the falling rain, and hence this belt is known either as the belt of rains, or of equatorial calms. The width across the ascending belt is several hundred miles, and though particles of dust or infusoria which enter on the south side may occasionally mingle with the air which enters at the north and thus be carried northward by the upward current, yet the habitual crossing of the two, as some have supposed, and the constant transfer of the vapor of the northern hemisphere to the southern, and *vice versâ*, is in accordance with no established principle of nature, and therefore cannot be admitted even as a plausible hypothesis.

On account of the heat evolved, the air in the ascending belt receives an additional momentum which carries it considerably beyond the point of statical equilibrium, and consequently it descends with a greater velocity, which is further accelerated by the cooling to which it is subjected at this high altitude by radiating its heat into celestial space. In its descent it brings down with it (at about the average latitude of 30°) the air north of this latitude, giving rise to a reverse current, and thus producing two separate systems, *A* and *B*. (Fig. 5.) The air at the foot of the descending belt at the latitude of 30° will press with greater weight than that of the average of the atmosphere, hence in this belt at the surface of the earth the barometer will stand higher, and while the belt of rains is called the middle belt of low barometer, the belt of 30° is frequently known as the belt of high barometer. At the foot of this belt the air will be pressed out toward the north and south; southward to supply trade winds and the air which ascends at the belt of calms, and northward to form the current from the southwest, (as shown in Fig. 6,) which latter is the prevailing wind of the north temperate zone.

We have thus seen that there would be a tendency to separate into the two systems *A* and *B*. (Fig. 5.) There would also be a tendency in the remaining air to separate at the point *g*, giving rise to the polar system *C*. Were the air within the circle of 60° north latitude entirely isolated from the other part of the atmosphere, a circulation would take place in this such as is indicated by *C*, the difference of temperature between the surface of the earth at the circumference of this circle and the regions in the vicinity of the cold pole would be sufficient to produce such a circulation. The column of air in the polar region, on account of its low temperature, would be denser and consequently heavier than the surrounding air; it would therefore sink down and spread out in every direction from the centre of the column; the air would flow in above to supply the level, while the current below would become heated as it passed southward and rise as shown at the point *g*. In its ascent it would tend to

carry up with it the surface air of the system *B*, and thus conspire with the downward motion at *f* to produce the circulation shown in system *B*.

The upward current at *g*, (as in the case of the upward current at the equator,) will tend to diminish the pressure of the air and produce a low barometer and an abnormal fall of rain, which perhaps will be more effective in helping on the circulation of the system *B* than the mere mechanical effect of the uprising of the current of *C*. The current at the surface of the earth in the system *C*, as is shown in Fig. 6, will curve to the westward on account of the increased rotation of the earth, and will therefore be almost in direct opposition to the system *B*. If we attentively consider the effect of the rotation of the earth on the system *B*, we shall find that as the current passes along the surface to the northeast as indicated in Fig. 6, it will begin to ascend when it comes near the parallel of 60°, (retaining however its easterly direction,) will gently curve round and pass southward as an upward current, and flow toward the equator as an upper northwest current, shown in the figure by the few longer arrows, indicating a northwest wind. The system *A* is the constant circulation of the trade and anti-trade winds. The system *C* depends upon a similar cause as we have seen, and is for a similar reason permanent in its character. Though but comparatively few observations have been made in the polar regions, the character of this system does not rest upon mere inference from the general principles we have given, but is conclusively established by the immediate results of reliable data. Professor J. H. Coffin, in his valuable memoir on "The Winds of the Globe," published by the Smithsonian Institution, inferred the existence of this system independently of theoretical conclusions. From the reduction of all the observations he was able to obtain, he conclusively proved that the resultant wind from the pole is from a northeasterly direction; and the same result is established by the discussion of the interesting series of observations made during the last expedition of Dr. Kane. These observations, which

have been tabulated for the Smithsonian Institution, under the direction of Professor Bache, by Mr. Schott, of Washington, give the same direction to the northern current at the surface of the earth within the polar circle.

That the prevailing motion of the system *B* is in the direction exhibited by the arrows, is abundantly shown by the fact of the prevalency of the southwest wind, particularly in the summer, over the whole of the temperate zone; and that this upper current of the same system is southward and eastward, or in other words from the northwest, is attested by aeronautic observations in this country, and in Europe. The celebrated American aeronaut, Mr. John Wise, (from the experience of upward of two hundred balloon ascensions,) has stated to the writer, that while the current at the surface of the earth is from the southwest, at a variable elevation of two miles or less, the wind becomes nearly due west, and at a still greater elevation it blows from the northwest. The direction of the intermediate stratum is probably due to the resultant action of the two, and this would naturally result from the almost constant action of ascending currents, passing with every fall of rain from the lower to the upper. A similar testimony is given for Western Europe by the aeronautic experience of Messrs. Green and Mason. According to this, though the prevailing wind at the surface is from the southwest, at an elevation of 10,000 feet the current is invariably from some point north of west. Moreover, observations on the direction of the ashes of volcanoes prove the same direction of the upper current. In the summer of 1783 the smoke of an eruption of a volcano in Iceland was diffused over England, Germany, and Italy. From another eruption of a volcano in the same island, in 1841, the ashes were carried by a northwest upper current and deposited on the decks of vessels in the Irish Channel.

Though the *prevailing* direction of the currents of the system is given in *B*, (in Fig. 5,) yet the stability of this system is by no means equal to that of *A*, or even that of *C*, since in some cases its direction is apparently entirely reversed. The northwest upper current, mingling perhaps

with the polar current, descends to the surface of the earth, (particularly along the continent of North America,) and probably gives rise to the phenomena known by the name of "Northers" and possibly also to the more violent north-east storms of the coast. While the reversal of this system takes place in one part of the earth, the more habitual motion may be continued in another, and in this way a mild winter in America, produced by a prevalence of south-westerly wind, may be accompanied with a severe winter, produced by northwesterly winds in some part of Asia, or Eastern Europe.

The belts and systems we have described are not stationary, but move north and south in different periods of the year with the varying declination of the sun. For example, the belt of rains is constantly almost directly under the sun, and moves north and south with the changing declination of that luminary, and thus divides the year in the tropical regions into two rainy and two dry seasons. The rain is produced (as has been abundantly shown) by the condensation of the vapor carried up by the ascending current of air; the dryness on each side of this belt is the result of the descent of the air which has been thrown out above, principally deprived of its vapor and increased in temperature both by the heat due to condensation and to that absorbed before it is thrown outward from the precipitated vapor. In the summer season, when the sun is on the northern side of the equator, the trade-wind system extends up on the ocean sometimes as high as 40° N. latitude. A similar movement takes place, but to a less extent, in the system of the temperate zone. From this movement it is evident that there is not only a variation of heat, but also of moisture and precipitation at different seasons of the year.

It is also necessary to mention that the belt of high barometer is interrupted across the continent of North America, and probably never passes farther north than the portion of the United States bordering on the Gulf. But on this point we cannot speak positively without more data and further investigation. It is certain however that on the Pacific side,

the belt of high barometer, (or that from which the air flows out on each side north and south,) in summer extends beyond the latitude of 40°, and thereby produces a wind from the north in this season of the year, while in winter it is found below Southern California, and thus gives rise along the coast and parallel mountains of the interior to a wind in the opposite direction, namely, from a southern point of the compass.

This is a sufficient explanation of the rain which falls at that season, since the currents from the south are laden with moisture which they deposit in their ascent along the slopes of the mountains towards the north.

On the drawing exhibiting the surface currents, (Fig. 6, p. 276,) the point P representing the geometrical pole, is not the centre of divergence of the aerial currents which settle down in this region. The latter centre is that of the cold pole, which probably on account of the unequal distribution of land and the currents of the ocean, does not coincide with the former.

Climate of the United States.

An application of the general principles we have given will enable us readily to comprehend the peculiarities of the climate of the United States, and to see how it must differ from that of other portions of the globe.

In order however to properly make this application, we must briefly recall what has been said in previous papers* on the circulation of the waters of the ocean, since they have a powerful influence in the distribution of heat and the modification of different climates of the earth. For the more definite comprehension of this, we have prepared a sketch of the western hemisphere, shown in Fig. 9, on which the direction of the principal currents of the northern oceans are denoted by arrows, and in explanation of these, we shall briefly recapitulate the general theory of the cause and motion of these currents.

If the equatorial regions of the earth were entirely covered

* [See *ante*, pp. 59-62.]

with water, the trade-winds blowing on each side and acting on the water would produce a current toward the west, encircling the whole globe. But since the region of the equator is crossed by continents, the continuous current we have

Ocean Currents of the Western Hemisphere.

FIG. 9.

spoken of is broken up and deflected right and left into extended circuits; the water blown from the coast of Africa along the region of the equator westward is divided into two currents, as represented in Fig. 9, one directed northward, and the other southward, by the projecting part of South America. The northern branch, as shown by the arrows, passes through the Gulf of Mexico, and impelled by the action of the surface wind and the rotation of the earth, makes a complete circuit, returning into itself along the coast of Africa, leaving in the centre a large area of stagnant water covered with weeds, and known by the name of the Sargasso Sea. The entire course of the waters in this

extended circuit is completed in about three years. In the Atlantic Ocean a branch is sent off from this circuit, which passes northward, impinges on the western coast of Europe, and probably skirts the whole circuit of the polar basin, from which it passes out on the west side at Behring's Straits.

Two similar systems of currents exist in the Pacific Ocean; that in the northern hemisphere passing from Central America along the equator to the continent of Asia, is deflected northward along the coasts of China and Japan, and returns to the equator along the western coast of North America.

Besides these great circuits from the equator, cold currents descend from the polar basin. One of these is represented by the arrows with double barbs between the Gulf Stream and the eastern coast of the United States; and a similar one descends along the coast of China between it and the Gulf Stream of that region. These are in part derived from the water which is discharged into the polar basin from the several rivers of the north, and probably in part due to a return portion of the equatorial currents. They skirt the eastern shores of the continents, because currents from the north (on account of the rotation of the earth) tend to move westward, while those from the south tend to move eastward.

The effect which these great currents of the ocean, (evidently the natural results of the system of winds which we have described,) produce on the climate of the United States, compared with that of Europe, can readily be appreciated. The elevated temperature of the water in the Gulf of Mexico, (higher than that of the water in almost any other part of the globe,) is retained by the Gulf Stream until it reaches the shores of the polar basin. The southwest winds which accompany and blow over the Gulf Stream share its temperature, and impart their warmth and moisture to Western Europe, giving it a climate far more genial than would be due to the latitude. The southwest and westerly winds which prevail over the surface of the United States serve to bear the heat of the Gulf Stream from our coast, and even when an easterly wind is produced by local

causes, which would bring the warm air of this stream to our shores, it is cooled by crossing the cold current we have mentioned, which reduces its temperature to the dew-point, and produces the peculiar chilly effect so familiar to the inhabitants of the Eastern States during the prevalence of a northeast storm: while on the Pacific coast the west winds from the ocean cross the comparatively cool current from the north and impart their mild and uniform temperature to the western slope of the Coast Range of mountains, giving rise to the remarkable fact of the summer temperature being the same for hundreds of miles in a north and south direction.

Were the whole of North America—from the Atlantic to the Pacific—a continuous plain, or were the surface diversified merely by eminences of comparatively small elevation, the moisture from the Pacific would be carried into the interior, and a much greater degree of fertility in the western portion of the Valley of the Mississippi would exist. In the actual condition of the continent however, the westerly wind which passes over the great mountain system extending from north to south along the western portion of the continent, deposits its moisture principally on the western slope of the Coast Range, and gives fertility and a mild climate to California, Oregon, Washington, and particularly to the regions farther north. The amount of rain which falls at Sitka, Russian America, amounts in some years to 60 inches. The remaining moisture which this westerly wind may contain is precipitated on the western slopes of the high ridges farther east, and when the current has passed over the whole Rocky Mountain system, it is almost entirely dessicated, and leaves the elevated plains east of the Rocky Mountains an arid region, so deficient in moisture as to be unfit for cultivation, unless by the aid of irrigation, with the exception of occasional oases, and along the borders of streams.

We have seen that two great systems of wind prevail over the United States, the upper from the northwest and the lower from the southwest. The latter carries the moisture

from the Gulf of Mexico and the Caribbean Sea over the whole of the Eastern States of the Union and the eastern part of the Valley of the Mississippi, and is therefore the principal fertilizing wind of the interior of the continent. Were the earth at rest this wind would flow directly northward, and would diffuse its vapor over the whole interior of the country to the base of the Rocky Mountains; but on account of the rotation of the earth it is thrown eastward, and bears its moisture in a northeasterly direction, leaving a large space, under the lee of the Rocky Mountains, (so to speak,) greatly deficient in this element of vegetable production.

These winds are shown on the accompanying map of the United States, which is copied in its principal features from a large map compiled by the Smithsonian Institution. In so small a sketch it is impossible to be accurate in the minute divisions; though it will serve to exhibit at a glance the relative proportions of the principal meteorological regions of the country. The northwest winds (those of the upper strata) are denoted by the heavier arrows with a circle on the end, and the lower ones—the surface or fertilizing winds—by the finer arrows. The dark portion of the map indicates the naturally woody regions of the country, well supplied as a whole with moisture from the fertilizing winds: the lighter shaded parts indicate rich arable prairie, along the streams of which, (where there is a local supply of vapor,) wood is found; but these districts as a whole have much less moisture than the naturally woody portions. The unshaded or white part of the map, within the boundary of the United States, indicates the regions so deficient in moisture that no dependence can be placed upon them for the purpose of agriculture. In some parts of them, where moisture is found, crops may be produced, but as a whole they are of little value in the way of affording the necessaries of human existence, and hence are incapable of sustaining other than a very sparse population. Portions of this unshaded part, on account of the nature of the soil, are barren and almost destitute of vegetation; while other parts, when occasionally watered by a fitful shower, yield patches of grass to which the buffalo by


REFERENCES.
Regions naturally woody.

his instinct is directed, but even these in the course of a few weeks are almost reduced to a powder by the drying influence of the unscreened rays of a powerful sun. What moisture rises from the evaporation of the rain which may fall on the regions indicated by the unshaded part of the map is constantly carried eastward instead of being precipitated again on the place whence it rose.

The direction of the several ridges of the Alleghany Mountains is parallel to that of the fertilizing wind, and hence these do not materially interrupt the southwestern currents, and are consequently sufficiently supplied with moisture, except in the more elevated valleys which are inclosed by a ridge at their southern extremities.

From the fact, abundantly proved by observation, that the vapor of the Pacific Ocean does not pass over the elevated crests of the Rocky Mountain system, it must be evident that the idea that the supply of the interior of the North American continent comes from the Southern Pacific by ascending to the cold regions of the top of the belt of rains is entirely untenable. The source from which the moisture of the interior is derived is principally the Gulf of Mexico. We shall endeavor to give in a subsequent Report an account of the climate of the several meteorological districts into which the United States may be divided; the remaining space allotted to this article will be devoted to a brief exposition of the storms of the Continent.

Storms of North America.—The two great systems of winds to which we have so frequently alluded as existing over the United States, present their meteorology in a simple form and on a very extended scale, while the general features of the phenomena of American storms are readily explicable on the principles of the theory propounded by Professor Espy. And first we may remark that on account of the height of the Rocky Mountain system, the storms or other commotions of the atmosphere which take place on its western side, are seldom if ever communicated to the air on the eastern; and this is a natural consequence of the principle which refers these commotions to the evolution of the

latent heat from portions of air charged with moisture. According to this view, an intervening region almost entirely without moisture will of necessity tend to intercept the progress of a storm, though it is not impossible that the drawing in of air on one side of a mountain of limited extent may cause a current across the mountain to supply the deficiency.

We think all the phenomena of the storms of the interior of this continent may be referred to disturbances in the equilibrium in the upper and lower strata of air. In the first place, all the disturbances of the atmosphere, however they may be produced, tend to move eastward over the United States, because this is the resultant motion of the great mass of current passing over the surface of this region. That the storms from the interior tend to move nearly east, with a velocity of from 20 to 30 miles an hour, is abundantly proved by the observations collected at the Smithsonian Institution, and the fact is interestingly and practically exhibited by means of the daily despatches gratuitously furnished this Institution by the Morse line of telegraph. These despatches are received every morning from the greater portion of the country east of the Mississippi River, and to render the information available in the way of predicting probable changes of the weather during the day or the following evening, a large map, containing merely the names of the places of observation, is attached to a wooden surface, into which, at each place, a projecting iron pin is driven. Small cards (previously provided) of about an inch in diameter, of different colors, to indicate rain, snow, clearness, and cloudiness, are attached to the map at the respective places of observation by means of the iron pins, and changed daily to correspond with the telegraphic despatches, so that an observer, at a glance, may see the condition of the weather at any portion of the country before mentioned. During the autumn, winter, and spring, if in the morning the visitor to the Institution observes a black patch indicating rain at Cincinnati, he may conclude that, in about twelve hours afterward, the same storm will reach Washington. Indeed so

uniformly has this been the case during the last year, that we have been enabled to decide whether it would be proper to advertise during the day the lecture to be given in the evening.

In summer it frequently happens that thunder storms commence their course at points intermediate between Cincinnati and Washington, and therefore it will not always follow that a clear sky in the morning at the former place will indicate a clear evening at the latter. But wherever the thunder storm commences it always moves eastward, or rather eastward inclining to the north, a direction which indicates that the direction of these circumscribed storms is principally governed by the motion of the lower stratum of air.

The extent of the interior storms, north and south, is exceedingly variable. In some cases a storm of not more than a hundred miles in width travels eastward along the lakes; and again at another time a storm of a similar width may commence at the south and move along the shore of the Gulf of Mexico. Again at other times the commotion appears to extend from some northern point in the British possessions, down to the Gulf of Mexico, and even farther south, and to move eastward, side foremost. In this motion the southern part of the storm first reaches the Atlantic Ocean, in the southeastern part of Georgia, and since the general trend of the coast is to the northeast, it is evident that the storm will appear to move from south to north along the coast, while in reality the whole system of disturbance is moving eastward, and will finally leave the continent at Newfoundland.

Another system of interior disturbances—which commencing apparently at the south and confined principally to the eastern coast tends to draw in the air from the Gulf Stream along the surface, to be carried outward again by the upper current,—gives rise to our northeast storms. These are however in a great degree intercepted by the Alleghany Mountains, and do not extend very far into the interior. According to a suggestion of Dr. Hare, these storms are due to a

heating and rarefaction of the air in the Gulf of Mexico, as probably are also the "northers" which descend from the western plains.

Still another system of storms, originating in the Caribbean Sea and following the general direction of the Gulf Stream, sometimes sweep over the peninsula of Florida, and overlap somewhat upon the eastern coast of the United States. These are the great hurricanes,—(or cyclones as they are sometimes called,) the character and nature of which have given rise to so much discussion.

During the warm months of summer almost every part of the United States is occasionally visited with very violent though exceedingly circumscribed commotions of the atmosphere known, as tornadoes or water spouts. These generally move in nearly the same direction,—toward the northeast, except perhaps on the borders of the Gulf of Mexico, leaving their narrow path, sometimes only a few rods wide, marked with the evidence of energetic action of a most destructive intensity. The question naturally arises, is it possible in the present state of science to give a rational explanation of the various commotions (apparently fitful and complex and without an adequate cause) manifested in the light and invisible aerial covering of our globe? Can the question be answered? How is it possible that the soft and balmy air, which offers scarcely the least resistance to the motion of a lady's fan, can yet exert a power sufficient to level with the ground the largest trees of the forest in a single minute, to the number of 7,000 in the space of a square mile, and this devastating energy continue, as it has been known to do, for a distance of many miles?

The phenomena of these violent circumscribed storms, which appear peculiarly marked in America, have been investigated with much careful and laborious research by Franklin, Bache, Loomis, Olmsted, Hare, Redfield, Espy, and others. We owe to the lamented Professor Mitchell, of North Carolina, valuable suggestions in regard to the motions of the air in storms of this character. Professor Bache was the first to make an actual survey of the track of a tornado, and

to protract on a chart the relative position and direction of the prostrated trees and the lines described by bodies which had been moved by the force of the wind. Mr. Chappelsmith, of New Harmony, Indiana, has furnished the Smithsonian Institution with an account of a tornado and a map of its path, on which are delineated, from actual survey, the position and direction of several thousand trees. Professor Loomis has also minutely described the effects of a number of tornadoes, and has besides investigated with much care and extended research the phenomena of several large storms. He was the first to adopt the system of preparing a series of maps illustrating the phases of the storm at different periods.

The laborious observations of the lamented Mr. Redfield, particularly in regard to the hurricanes of the Atlantic Ocean, have intimately connected his name with the history of meteorology, while the theoretical expositions which have so long occupied the attention of Mr. Espy have done admirable service to the cause of the same branch of knowledge.

The controversial papers of Dr. Hare, bearing evidence of his great logical powers, served to give precision to the views of those engaged in these investigations, and thus to eliminate error as well as to advance the truth. In speaking of those who have given interesting expositions of the general facts of the meteorology of North America, we ought not to omit mentioning Mr. Robert Russell, of Scotland, who visited this country a few years ago, and who has since published a work on the agricultural resources of the United States and its meteorology, which is alike characterized by accuracy and sagacity of observation as well as by candor and justness of opinion.

The facts which have been gathered from the researches of those we have mentioned, as well as from other sources, ought to be sufficient to furnish an induction of the principles on which these phenomena depend; and although no theory at a given time in the history of a progressive science can be considered as perfect, yet we believe the general principles on which the disturbances we have mentioned depend have been successfully developed by Mr. Espy; and though

in subordinate particulars modifications will be required, yet we think the general propositions of his theory will stand the test of time.

As a general rule previous to the commencement of an extended storm (during winter), the surface current is from the southwest or some southerly direction, the temperature rises and the pressure of the air diminishes as indicated by the fall of the barometer. This state may continue for several days, and we think it is produced by the southerly current increasing in quantity, in velocity, and depth, thereby rendering the stratum of air next to the surface of the earth abnormally warm and moist, and consequently lighter, while the upper current remaining the same, the atmosphere above the surface of the earth gradually assumes a state of tottering equilibrium. This condition, according to Mr. Espy, is not brought about by the gradual diminution of the density of the lower stratum but by the increased density of the upper strata, due to the radiation into space of the latent heat which had been evolved during a previous storm. We think however that both causes are operative. This instability or tottering equilibrium will first take place at the far west, on the western plains east of the Rocky Mountains, since (as we have before said) the commotions on the western side can be but slowly propagated across the high mountain system. A storm then consists of the ascent of the lower current into the upper and the gradual transfer of the commotion of the air eastward. To take the simplest case, let us suppose the storm to be of circumscribed character, like that of a water spout or thunder storm. In this case after the unstable equilibrium has been produced, the slightest disturbance, such as the passage of the lower current over a slight elevation or over ground more highly heated than the adjoining will tend to establish an upward current. The light, warm and moist air below will be buoyed up with great rapidity and as it ascends will come under less pressure and will expand into a larger bulk. If it were perfectly dry it would again be in equilibrium, its bulk would be increased, its density would be diminished to that of the air to which it

had ascended, and its temperature would be the same as that of the surrounding stratum. But since it contains moisture and in expanding becomes colder, a portion of the vapor will be condensed, and in this condensation will give out its latent heat. Hence the air of the column will be warmer than that of the surrounding atmosphere; it will consequently rise to a greater height, again expand, again become colder; another portion of vapor will be condensed, and another amount of latent heat evolved, and thus the air will rush up with an accelerated velocity, and probably gather momentum sufficient to carry it to a height greater than that due to its buoyancy alone. The condensed vapor will fall in rain through the base of the cloud, the air on either side of the storm will be forced out from the uprising column into the surrounding air, and while the pressure at the base of the column will be diminished, that on each side will be increased, hence the barometer will be frequently found to rise slightly before the approach of a storm and to sink rapidly as the centre of the uprising column approaches the place of observation.

A series of observations has been made at the Smithsonian Institution to determine the variations of the barometer during the passage of thunder storms, and in every case in which observations of this kind have been obtained, a sudden fall has been observed in the barometer, and at the moment of the descent of the rain a slight elevation, followed again by a depression and then a rise, until the normal pressure of the day, or perhaps a little greater, has been obtained. The intermediate rise taking place at the moment of the fall of the rain may be properly attributed to the momentum of the drops as a sufficient cause.

Fig. 10 is intended to illustrate the conditions and phenomena of a commotion of this kind. The dotted space, *c d*, at the bottom represents the lighter atmosphere, consisting of the warm southwest current sur-charged with moisture; above this the parallel horizontal lines, *a b*, and the arrows, indicate the direction and position of the upper western current. The ascending column is represented by the upward turned arrows,

FIG. 10.

and the shaded portion above exhibits the cloud formed by the condensed vapor which is thrown outward on each side. The rain falling in the axis of the uprising column by its weight forces out the air in the direction of the arrows at the foot of the column.

When the air is saturated with moisture in warm weather, and especially when the sensation called closeness is observed, the rushing up of the column through a confined space may be so violent that drops of water may be carried up beyond the point of congelation and be converted into ice, and these will be thrown out on each side, exhibiting the phenomenon often observed in storms of this character, of two streaks of hail along the course of the tornado. In some cases these pieces of frozen water will be caught up by the inblowing air below and carried up again, perhaps several times in succession, each time receiving new accretions, and thus large hail stones will be formed exhibiting a concentric structure in which the centre will be of a light spongy consistency, and this succeeded by a stratum of transparent ice and this again by another stratum of snowy appearance, and so on, the outer surface being covered with large projecting crystals of solid ice. These facts are in strict accordance with what we might have predicted from the theory we have

adopted. If several large drops of water come in contact, and by their attraction rush into one larger drop, and if this be borne up so high that it begins to freeze, crystallization will commence at the surface, the air in the water will be driven inward as the solidification proceeds, and when the freezing is completed it will give a spongy appearance to the nucleus of the hail stone. As the hail stone is carried up a second time it will gather in its ascent another quantity of water which will again begin to freeze and produce the spongy envelope, inclosing the stratum between it and the coat of pure ice, surrounded by a stratum of solid ice, and so on. The number of concentric envelopes will indicate the number of times the hail stones have been carried up, and the collision of the stones in their ascent and descent will give rise to the peculiar noise which is heard during the passage of a storm of this kind.

The ascent of bodies in the centre of the up-moving column, and their being thrown out at the top, is not a mere matter of speculative inference, but rests upon direct observation. Bodies are seen to be carried up in the middle of the ascending column and thrown out as we have described; but above all Mr. Wise, the celebrated aeronaut, gives an account of what took place on the occasion of his balloon being drawn into the ascending column of a thunder storm. The balloon was carried up to a great height, thrown out on one side, sunk gradually down, was caught again by the in-blowing current which was rushing in to supply the column, again violently carried up, and again thrown out, and this several times in succession.

We have here, in accordance with the theory of Mr. Espy, a true, simple, and sufficient explanation of the production of hail, which takes place in the hottest and most sultry weather, when the air is most highly charged with moisture, and consequently when it contains the greatest amount of latent ascensional power. The vapor which ascends is derived from the moisture which a short time before existed at the surface of the earth, and since the ascending column usually carries up with it a quantity of fine dust, gravel,

pieces of leaves, &c., these are found in the nucleus of the hail stones.

In order that a storm of this kind may be attended with hail, it is necessary that it be of considerable violence, in order that the drops of water may be carried up to a sufficient height, and hence, as we have said before, this phenomenon occurs usually in the warmest and most sultry weather.

The writer is enabled to give the foregoing explanation of the nucleus and the alternate spongy layers of large hail stones from the effects he obtained by freezing water in a glass bulb. The freezing commenced at the exterior surface, to which the axes of the crystals were at right angles. The air contained in the water was forced in before the advancing crystallization, and formed at the centre of the globule a spongy mass precisely similar to that which formed the nucleus of the hail stone.

When the uprising column assumes the form of a tornado, it is more circumscribed, and is we think generally accompanied by a whirling motion. The power of the current however is in an upward direction. The gyration is an accidental circumstance, while the upward motion is an essential one; and the whole power of the tornado to produce mechanical effects is in this direction; hence as it passes along over the surface of the earth, the air flows in on every side to supply the up-moving column, trees are drawn in by the force of the centripetal current, and thrown with their tops towards the path of the tornado. The writer had an opportunity, on one occasion, of examining with Professor Bache the effects of a tornado after it had passed through an orchard. The trees were all prostrated in a strip of about four rods in width, with their tops inward toward the middle of the path. The whirling tends to contract the dimensions of the column, and to give it the peculiar appearance of an inverted cone descending from the clouds. The air which rushes into the revolving cylinder, charged with moisture, is immediately expanded, consequently cooled, and its vapor condensed into visible clouds, which gives rise to the peculiar appearance of the descending trunk.

The tremendous ascensional power which is exhibited in storms of this kind, although almost exceeding belief, is nevertheless in accordance with the established dynamical principle of the accumulation of momentum in cases of the continued action of a constant force. We are all familiar with the velocity given to an arrow by a simple propulsion of the breath along the interior of a blow-gun. In this case the air presses against the end of the arrow, at first with just sufficient force to move it; but the momentum it has thus acquired is retained, it receives another pressure from the air, retains the effect of this, and so on, until it leaves the other end of the tube with the accumulated momentum acquired during its whole passage through the interior of the gun. In the same way the air, as it approaches the uprising column below, commences its ascent with an amount of momentum which is constantly increased by continued pressure from behind. The ascensional momentum therefore becomes so great as to furnish a ready explanation for all the exhibition of mechanical power which is so frequently witnessed in storms of this character in our climate. On account of the rarefaction of the air in the centre of the storm in cases where it has passed directly over head, buildings are instantly unroofed, the sides are thrown outward, as if by the action of gunpowder, chests are broken open, and corks forced from empty bottles, in which they have been tightly fitted. In these cases the outward pressure being in part removed, the unbalanced repulsive energy of the atoms of the air within the edifice causes the outward explosion. The force of this outward tendency will not be surprising when we reflect upon the great pressure of the atmosphere in its normal state, which is equal to more than 2,000 pounds on every square foot of surface, and which frequently and suddenly experiences a reduction of a twentieth part of at least this amount, or in other words, of 100 pounds to the square foot—an unbalanced force abundantly sufficient to produce the effects we have mentioned.

Dr. Hare attributed the violent upward motion of the air in tornadoes to a peculiar electrical state of the atmosphere

in which, while the air was highly positive, the earth was negative, and the bodies carried up were repelled from the earth and attracted by the cloud, as in the case of the dancing figures between the two plates, one of which is connected with the prime conductor of an electrical machine and the other with the earth. We think however with Mr. Espy that electricity is altogether a collateral result,—an effect of the storm and not its cause; it is probable however that its presence tends to modify the appearance and produce phenomena of a subordinate character. It is well known that when a kite to which is attached a metallic string is sent up to a considerable height above the earth, the wire becomes highly charged with electricity, even in a clear day when not a cloud is visible; this effect is due to what is called induction. The positive electricity of the upper atmosphere drives the natural electricity of the wire from its top to its bottom, hence the upper end of the wire will be negative and the lower end positive; a similar effect must be produced on the cloud formed by the uprising column and on the column itself, the two form a continuous conductor of immense height, and hence like the wire must become charged at the lower end with positive electricity of great intensity, which will tend to elongate the trunk downwards by repulsion, and which will give occasional discharges to the earth as the tornado passes over good conducting substances.

The terrific and appalling grandeur of the tornado strikes the beholder with astonishment and awe, now pausing fitfully as if to select with malignant caprice the objects of its unsparing fury, now descending to the earth, and again drawing itself up, with its deep, loud, and sullen roar; its mysterious darkness; its apparent self-moving, resistless revolutions; carrying upwards branches of trees, beams of houses, and large objects of every description; its impetuous downward rush to the earth, and then again up to the sky, its sublime altitude, sometimes erect and at other times inclined; its reeling and sweeping movements; all these and more to be adequately conceived must be actually witnessed.

The thunder storm differs from the tornado in its less concentration, and consequently in the less intensity of its violence. It occurs usually in the United States in the after part of a sultry day, when the air has attained its maximum amount of vapor, and has therefore assumed a condition of instable equilibrium. These storms are usually produced over a considerable extent of country on the same day, and occur nearly at the same hour for several days in succession, and probably serve to restore a more stable equilibrium to the air, and thus perform the office of the great winter storms which sometimes regularly succeed each other at given intervals. Their general course is eastward, but they sometimes deviate from this direction to a certain extent, apparently on account of the attraction of water courses; they partially exhaust, carry up and precipitate the moisture of the atmosphere, but sometimes leave the air immediately afterwards in a sultry condition. We hope to be able to give in another article an exposition of the electrical phenomena exhibited by thunder storms, but we may mention here the fact of the almost instantaneous fall of rain after each peal of thunder. It has been supposed that the drops of rain in this case were produced by the agitation of the discharge of lightning; but a little reflection will render it evident that the rain must have commenced its rapid descent before the discharge took place, since it follows the flash at so short an interval that we must suppose that it commenced to fall previous and not subsequent to the discharge. It is more probable that the fall of rain, on account of offering a conducting medium for the electricity, is the cause and not the consequence of the discharge in question.

The great interior storms we have mentioned usually commence at the Far West, even at the base of the Rocky Mountains, and generally occur in November, December, January, February and March. They are sometimes of great extent in a north and south direction. One of these storms, that of 1836, which was investigated with so much ability by Professor Loomis, reached from the Gulf of Mexico to unknown regions in the north. They are of varying breadth, some-

times several hundred miles across, and the cloudiness produced frequently overspreads simultaneously a considerable portion of the eastern part of the United States.

In common with nearly all the commotions of the atmosphere on the North American continent, they move eastward, at the rate sometimes of thirty-five miles an hour. In some rare instances the horizontal axis of the storm in a north and south direction is nearly a continuous straight line, and moves side foremost toward the east, in the form of an immense wave, or rather undulation. The pressure on the middle of this wave, on account of the uprising air, is less than the normal pressure of the atmosphere, while on either side, and particularly on the east, it is greater.

This pressure on the front and rear of the storm is due to the spreading out above of the air which has been carried up in the ascending current, and is greater on the east side of the storm on account of the action of the westerly current in which the whole commotion is carried forward. The approach of the storm is therefore generally indicated by a rise of the barometer, which is succeeded by a subsequent fall, and also by an increase of temperature due to the radiation from above of the latent heat evolved, and also by the increased pressure of the air forced out above. Sometimes the horizontal axis of the storm is curved, and again, which is of more frequent occurrence, broken up into a number of separate parts, forming altogether a system of which the several portions slightly vary in direction and velocity in their motion to the east.

These great storms, though of the same general nature as the thunder storm, are attended with an entire subversion of the upper and lower strata of the atmospheric ocean. After one of them has swept over the continent the commotion is immediately succeeded by a westerly wind, a great reduction of temperature, and a great increase in the degree of dryness of the air. We have endeavored to give an idea of the motions of the strata of the atmosphere accompanying these changes in Fig. 11, which exhibits an imaginary section of the currents in an east and west direction.

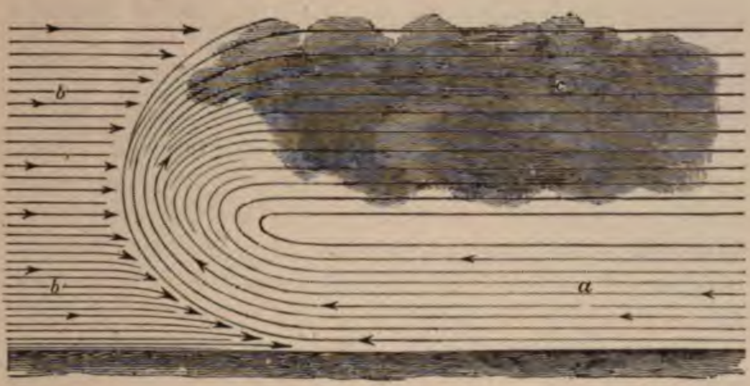

FIG. 11.

Previous to the commencement of the storm there exists over the surface of the United States a lower stratum of air moving from southern points of the horizon, and over this at an elevation of two or three miles the constant current from the west continues its habitual and un-interrupted course. The lower stratum, coming principally from the Gulf of Mexico, is abnormally warm, moist, and light, while the super-stratum is in its usual condition, and the whole is therefore in a state of unstable equilibrium. At the far west this lower stratum begins to be invaded by the denser air from the polar current, which coming from the northwest and mingling with the upper current, presses under, and turning the moist current upward produces an ascending column, or rather wall, which mingling with the upper current is carried rapidly to the east. The upper current is continued with varying energy, and by the condensation of the vapor from the lower, forms clouds and rain, which are carried in advance to the east, as the whole system of disturbance is borne in the same direction by the ordinary eastward flow of the upper current of the aerial ocean. The primary lower current is shown in the figure by the stratum *a;* the upper current, which has filled the whole space on the west down to the earth, by *bb;* the portion of the primary upper current into which the stratum *a* has ascended

and in which its vapor has been condensed into clouds and rain is represented by *c*.

As the storm advances eastward, it leaves the country behind it entirely covered with the westerly current, and in this way carries before it to the ocean the greater portion of the vapor with which the lower stratum, previous to the commencement of the storm, was saturated. The rain which falls at any given place is formed of the condensed moisture which a few hours previous existed at the surface of the earth in the same spot or its vicinity.

We have represented in Fig. 11 the whole cloudiness thrown eastward in advance of the storm, but in some cases, with a more energetic upward motion, a part of the ascending air will be thrown out to the west above; but this can scarcely ever take place to the same extent as on the eastern side. After the upward moving column has passed over a given place, the wind which was previously from the east, will suddenly change to the west, the sky will become clear and a great reduction of temperature follow. The whole effect then is due to the instable equilibrium produced in the air by the introduction of moisture and the accompanying elevation of temperature, together with the subsequent evolution of the latent heat. A similar condition of the atmosphere preparatory to the formation of another storm will gradually be re-produced. The westerly wind will again be buoyed up by the warm air from the south, it will therefore disappear at the surface of the earth, at which a calm will at first exist, the southerly wind will increase in velocity, the thermometer and hygrometer will indicate a higher temperature and increasing amount of vapor, the barometer will fall, and after a given interval another instable equilibrium will be produced, to be followed by another subversion of the strata of the aerial ocean and the repetition of all the previous phenomena. The intervals between two successive storms will also depend on the time of radiation into celestial space of the evolved heat, in order to reduce the upper stratum to its normal condition of temperature and density; but the time required to produce these effects is frequently

in winter very nearly the same for several successive periods. For example, most persons can remember the successive occurrence of a series of storms on Sundays. In one case we recollect this to have taken place six times in succession. There is nothing in this particular day to induce the occurrence of a storm, but merely it will be more likely to be remembered when it happens at this time; and although the interval between two storms may not be precisely seven days, yet it may differ so little from this that a part of the first and sixth Sundays may be included in the cycles of disturbance.

The wind as a general rule tends to flow towards the axis of the storm from each side, but at the surface of the earth, diversified with hills and valleys, the direction is far from being as regular as at first sight might be expected. Besides this, since the commotion of the atmosphere is usually divided into a number of separate groups—each having a separate ascending column or belt to which the in-blowing air is directed,—the arrows on the map indicating the direction of the winds generally present a very complex system of currents. On this account also, the rain does not simultaneously fall along an extended line from east to west but in separate places, the position of which is determined probably by the greater amount of moisture, and consequently the more intense action of the ascending current. As the storm approaches the eastern part of the United States however the in-blowing air to supply the up-moving current draws in the air from the ocean, charged with moisture; which being constantly supplied, the action may continue for several days, and the storm may perhaps become stationary, giving rise to prolonged easterly currents.

It would appear however from observations at the Smithsonian Institution, that the northeast storms are produced by the rarefication of air on the east side of the Alleghany Mountains, being frequently independent of a previous interior storm from the west.

A considerable number of storms has been mapped in accordance with the plan first adopted by Professor Loomis,

exhibiting on the successive maps by colors the positions and movements of the lines of equal pressure and of equal temperature. We have not been able to find however (except in very rare cases) the advance of the storm side foremost in a continuous line. The conditions presented are similar to those we have described, namely a series of centres of commotion advancing eastward.

The storms next to be noticed are those spoken of as hurricanes, or cyclones, the true character or nature of which has given rise to much discussion between the advocates of the two rival theories, of an entirely horizontal gyratory motion of the wind on the one hand, and an in-blowing to a central area and upward motion of the air on the other.

Much of this discussion undoubtedly arose from the want of precision in the earlier conceptions of the motions of the air when referred to the surface of the earth, as in the case of a gyration, and in many cases to the ambiguity of the language in which these views were expressed. While Reid and Piddington supposed the motion of the wind to be in concentric continuous circles, and Mr. Espy at first in direct radial lines towards the centre, Mr. Redfield finally adopted an intermediate view, namely of a spiral inward motion. We are entirely convinced from the observations which have been collected at the Smithsonian Institution in regard to the large interior storms that they are not rotatory, and that when the gyrations do take place, (as they must in some cases on account of the in-blowing currents from all directions not exactly opposing each other,) the gyration is a secondary motion, the principal force being exerted in an upward direction. We are unable to conceive of any adequate cause of the great and continued velocity of the air in a circle of several hundred miles in diameter except that which is due to the heat evolved by the condensation of the vapor with which this portion of the atmosphere is saturated. This appears to be the true and sufficient source of the great motive power, and to afford (when connected with the rotation of the earth) a complete explanation of all the phenomena. These storms as we have said commence in

the Caribbean Sea, and describe a curve on the surface of the earth almost precisely the same as that which would be exhibited by the projection on a horizontal surface of the path described by an atom of air in its ascent at the equator, in its passage westward, and in gradually curving round toward the east. Mr. Redfield has shown that these curves in whatever longitude of the northern hemisphere the hurricanes have occurred, are of precisely the same character.

If it be admitted that the motive power of this violent commotion of the atmosphere is due to the evolved heat of the moisture of the air, it will follow that such storms will be most frequent and of greatest intensity in portions of the earth where the relative amount of moisture is greatest, and that they will therefore be found in the greatest number in the heated and moist air directly over the Gulf Stream. The atmosphere over this area must be in the highest degree in a state of tottering equilibrium, since the air rising from the heated surface along the axis of the stream must be much more highly charged with moisture than that on either side. Observation and theory are here in accord.

These storms sometimes overlap the eastern coast of the United States and produce great destruction of property along the seaboard, and frequently a loss of life and shipping in the region of the Gulf Stream.

Hurricanes of the same character are found in the southern hemisphere, describing similar curves, which turn south however from the equator round to the east, in an opposite direction to that of the curves described by the hurricanes of the northern hemisphere. The space to which we are limited in this article precludes a more minute discussion of the phenomena which have been observed, and the opinions which have been adopted, in regard to these storms. We may have an opportunity of resuming the subject on some other occasion.

In this paper we have endeavored to give an exposition of the general principles of the meteorology of the United States, reserving for a future report a more detailed account of the climatology of its different portions. We have especially

endeavored to exhibit our views of the theory of Professor Espy and to show its applicability to the explanation and in some cases to the prediction of the great commotions of the atmosphere. We think this theory has not received the attention from foreign meteorologists which its merits demand, and this perhaps has arisen from the fact that it has not been presented to the public in a form which would commend it to the immediate attention of scientists. It has been frequently coupled with propositions for the artificial and economical production of rain, which—however well based on scientific principles—would be too uncertain and too expensive to render them of any value in a practical point of view: and it must be confessed that the language of Mr. Espy in regard to the proofs of the truth of his theory, and of its great value as a scientific generalization, has occasionally been such as to awaken opposition to it rather than to secure its approval and final adoption.*

[* Fifty-six pages of Meteorological Tables following this part are omitted in the present re-print.]

METEOROLOGY IN ITS CONNECTION WITH AGRICULTURE.

PART V.—ATMOSPHERIC ELECTRICITY.

(Agricultural Report of Commissioner of Patents, for 1859, pp. 461–524.)

In this paper we intend to give a sketch of the general principles of atmospheric electricity;—a branch of meteorology which has attracted in all ages more attention, and has been regarded with more interest, than perhaps any other.

The vast accumulation of electricity in the thunder cloud, and the energy exhibited in its mechanical, chemical, and physical effects, have impressed the popular mind with the idea of the great efficiency of this agent in producing atmospheric changes, and have led to views of its character not warranted by cautious induction. It is frequently considered sufficient in the explanation of an unusual phenomenon to refer it simply to electricity. References of this kind however are by no means satisfactory, since the scientific explanation of a phenomenon consists in the logical reference of it to a general law; or in clearly exhibiting the steps by which it can be deduced from an established principle. Electricity is subject to laws as definite and invariable as those which govern the mechanical motions of the planetary system. In one respect indeed, there is a great similarity between them, and it will be seen in the discussion of electrical phenomena, that these are referable to forces similar in action to that of gravitation; and that the mathematical propositions which were demonstrated by Newton in regard to the latter, have been applied with admirable precision to represent those of the former.

In giving a general exposition of a subject of this kind, two plans may be adopted: either a series of facts may be stated, and from these a theory gradually developed by a careful induction, or we may begin with the general principles or laws which have been discovered, and from these deduce the facts in a series of logical consequences. The first method is called induction, the second, deduction; and they

are sometimes known by the more scholastic names of analysis and synthesis. The first method may perhaps be considered the more rigid, and where a systematic treatise on a subject is intended, and ample space allowed for its full discussion it might be preferred; but where the object is to give the greatest amount of information in the shortest time, to put the reader in possession of the means through which by his own reflection he can deduce from a single principle hundreds of phenomena, and declare—prior to experiment or observation, what will take place under given conditions, the latter method will be the proper one to be adopted.

It is impossible however to state a principle of very general application without employing an hypothesis or an assumption which though founded on strict analogy may possibly not be absolutely true. We adopt such an hypothesis temporarily, not as expressing an actual entity, but as a provisional truth which may be modified or even abandoned when we find it no longer capable of expressing all the phenomena. All we assert positively in regard to such an hypothesis is that the phenomena to which it relates and with which we are acquainted at the time exhibit themselves as if it were true.

When an assumed hypothesis of this kind furnishes an exact expression of a large number of phenomena, and enables us beforehand to calculate the time and form of their occurrence, it is then called a theory. The two terms—hypothesis and theory—though in a strict scientific sense of very different signification, are however often confounded and otherwise mis-applied. *Theory*, in common language, is frequently used in contradistinction to *fact*, and sometimes employed to express unscientific and indefinite speculations. The cause of truth would be subserved if these terms were used in a more definite and less general sense; for example, if the term *speculation* were restricted to those products of the imagination which may or may not have an existence in nature; the term *hypothesis* to suppositions founded on analogy and which serve to give more definite conceptions of laws; while the term *theory* is reserved for generalizations

which although presented in the language of hypothesis, yet really furnish the exact expression of a large class of facts.

Hypotheses—well conceived and properly conditioned by strict analogy, not only enable us, as above stated, to embrace at one view a wider range of phenomena, but also assist us in passing from the known to the unknown. When rightly used they are the great instruments of discovery, giving definite direction as to the experiments or observations desirable in a particular investigation, and thus marking out the line of research to be pursued in our endeavors to enlarge the bounds of the science of our day. We think that the tendency of some minds, instead of being too speculative is too positive; and while on the one hand there is too much of loose, indefinite, and consequently of useless speculation intruded upon science, on the other hand an evil of an opposite kind is frequently produced by attempting to express scientific generalizations of a complex character without the aid of proper hypotheses; and to this cause we would principally ascribe the looseness of conception which frequently exists in well-educated minds as to the connection and character of physical phenomena.

In accordance with the foregoing remarks we shall make use of a theory to express the well-established principles of electrical action, and from this endeavor to deduce such conclusions as are in strict conformity with the observed phenomena. The intelligent reader who attentively studies this theory, and exercises his reasoning faculties in drawing conclusions from it, will be able not only to explain many remarkable appearances which would otherwise be entirely isolated, but also to anticipate results, and to adopt means to prevent unpleasant occurrences or to ward off dangers.

The theory which we shall adopt is that invented by Franklin, and extended and improved by Epinus and Cavendish. It is sometimes called the theory of one fluid, in contradistinction to the theory of Dufay, of two fluids. The two theories however do not differ so much as at first sight might be supposed, and when expressed mathematically are essentially the same.

No part of the writings of Franklin exhibits his sagacity and his power of scientific generalization in a more conspicuous light than his theory of electricity. The talent to discover isolated facts in any branch of science, although possessed by few, is comparatively inferior to that characteristic of mind which leads to the invention of an hypothesis embracing in a few simple propositions whole classes of complete phenomena.

Theory of Electricity.

According to the theory of Franklin all the facts of ordinary electricity may be referred to the action of a subtle fluid, which perhaps fills all inter-planetary space, and may be the medium of light and heat. In order that the phenomena of electricity may be represented by the mechanical actions of this fluid, it is necessary to suppose that it is endowed with certain properties and relations which may be expressed in the following series of postulates:

1st. The electric fluid (or æther) consists of atoms so minute as to exist between the atoms of gross matter.

2d. The atoms of the fluid repel each other with a force varying inversely as the square of the distance; that is, when the distances are 1, 2, 3, 4, 5, &c., the forces are 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{25}$, &c.

3d. The atoms of the fluid attract the atoms of ordinary matter with a force also varying inversely as the square of the distance.

4th. The atoms of gross matter devoid of electricity tend to repel each other also with a force inversely as the square of the distance.

5th. The atoms of the fluid can move freely through certain bodies of gross matter, such as metals, water, &c., which are hence called conductors, and cannot move, or but very imperfectly, through other bodies, such as glass, baked wood, dry air, &c., which are called non-conductors.

6th. When each equal portion of space has the same amount of electricity, and each body in it has so much of the same fluid as to neutralize the attractions and repulsions of the

matter, there are no indications of electrical action; and when the attractions and repulsions are thus neutralized a body is said to be in its natural condition.

7th. The electrical equilibrium may be disturbed by friction, chemical action, change of temperature, &c., or in other words (by these and other processes) the fluid may be accumulated in one portion of space, and rendered deficient in another, and in this case electrical action is exhibited.

8th. The phenomena are of two classes, namely statical, or those of attraction and repulsion, in which the electricity is at rest, and dynamical, or those in which the redundant electricity of one portion of space is precipitated into that of another in which there is a deficiency.

9th. When the electrical equilibrium has been disturbed and a body contains more than its share of electricity, it is said to be positively charged; and when it contains less, it is said to be negatively charged or electrified.

The fourth proposition of this theory was added by Cavendish, in England, and by Epinus, in Germany, and was found to be necessary in order to render the several parts of the theory (as given by Franklin) logically consistent with each other. At first sight it appears to be contrary to the general fact of the mutual attraction of all bodies, but it must be observed that when gross matter exhibits attraction it is in its normal condition, and that since the electrical force is infinitely more intense than that of gravitation the latter may be a residual phenomenon of the former.

According to this theory, there are two kinds of matter in the universe,—ætherial or electrical matter, and gross (or as it is frequently called by way of distinction,) "ponderable" matter. The two however may have the same essence, and differ from each other only in the aggregation of the atoms of the latter; or what we call gross matter may be (as suggested by Newton,) but a segregation or kind of crystallization of the ætherial matter in definite masses. Each kind of matter is in itself entirely inert, has no power of spontaneous change of place, and is equally subject to the laws of force and motion. A mass of ordinary "ponderable" matter,

when once at rest, tends to continue at rest until put in motion by some extraneous force; so also the electrical fluid, when at rest, tends to remain at rest, and only moves in obedience to some impulse from without. From this theoretical inference, which is in accordance with all observation it is an error to suppose that electricity is an ultimate power of nature, being in itself the cause of motion. Like the air, it is inert, and has no more tendency to spontaneous motion than this or any other fluid which may receive and transmit impulses, or which may have its equilibrium disturbed, and in the restoration of this equilibrium, give rise to motion and produce mechanical effects.

Perhaps some currency is given to the idea that electricity is not subject to the mechanical laws which govern the actions of gross matter, because it is called an "imponderable" agent, and has thus assigned to it a kind of semi-spiritual character. The term "imponderable," though convenient, is not properly applied, since it indicates a distinction which may possibly not exist. If electricity is in reality a fluid, it might exhibit weight, could it be so isolated and condensed as to become sensible to our balances. But whatever may be its nature, the phenomena which it exhibits can be referred to mechanical laws; and it is in order that such a reference may be definitely made, that the hypothesis of a fluid is adopted. For a similar reason the phenomena of light and radiant heat are referred to the vibrations of the ætherial medium, and it is in this way that the laws of motion which have been deduced from the study of gross matter have been so successfully applied to them, and it is only so far as the facts of what are called the "imponderable" agents are brought under the category of mechanical laws that they take the definite form which entitles them to the name of science.

Theoretical Deductions and Illustrations.—We do not intend to develop from the theory we have presented a complete system of electricity, but to give such deductions from it as will put the intelligent reader in possession of the principal known facts of atmospheric electricity, and particularly those which relate to thunder storms.

In the first place, if the ætherial medium in its ordinary state of diffusion fills all space, then it must be evident that when a body is charged with more than its natural share, a portion must be drawn from space around, and hence what one body gains other bodies in the vicinity must lose, or in other words there must always be as much negative excitement as positive. To exhibit this, as well as to illustrate some of the effects of the disturbance of the electrical equilibrium, provide two strips of glass an inch in width and twelve inches long, and on the end of one of these fasten with beeswax or sealing-wax a piece of woollen cloth about an inch and a half long; if the glass slips are warmed and rubbed together, as shown in Figure 1, and afterwards separated, they will exhibit signs of electricity. If the strip of glass of which the end is naked be brought near a pith-ball *C*, suspended by a single fibre of non-conducting silk, so that the electricity which may be communicated to the ball cannot escape, the ball will be attracted, and immediately afterwards repelled. If now the end of the other glass having the woollen cloth on it be brought near to the same ball, attraction will take place at a considerable distance. The one slip of glass will constantly attract, while the other will as constantly repel the ball. If however the two glasses be placed in contact as they were when first rubbed, and thus presented to the ball, neither attraction nor repulsion will be exhibited.

Fig. 1.

These results are in strict accordance with the theory we have adopted. By rubbing the glass and woollen cloth against each other the electrical equilibrium is disturbed—

a portion of the natural electricity of the cloth is transferred to the glass; the latter receives a positive charge of electricity, while the woollen cloth loses a portion of its natural share of the fluid, and assumes the negative state; and since the slips of glass, as well as the surrounding air, are non-conductors, the redundancy of the one cannot escape, nor the deficiency of the other be supplied, and therefore the charged condition of each will continue for a considerable time, particularly if the air be perfectly dry.

When the glass plate is made to touch the ball a portion of electricity accumulated on the surface of the former is transferred to the latter, which has then more than its natural share; and since atoms of free electricity repel each other, the ball will apparently be repelled from the glass; and also because there is an attraction between free electricity and un-saturated matter, the cloth which is in this condition will attract the same ball. When the two slips of glass are brought together and presented as a whole the attractions and repulsions may still be considered as existing, but since they are equal and opposed they entirely neutralize each other, and no external effect is perceptible.

The neutralization of the two opposite forces in this experiment affords an illustration of the condition of a body in its natural state. Although it contains a large amount of the fluid no action is produced on other bodies in their natural condition because the attractions and repulsions just balance each other.

For exhibiting the most important statical phenomena of electricity, and for verifying the deductions from the theory, we may employ a solid glass rod of about fifteen inches in length, and a rod of sealing-wax or of gum shellac of the same length. If these be well dried, held by one end and rubbed with a piece of woollen cloth at the other, electrical excitement will be produced. Instead of a solid glass rod a tube may be employed, provided the interior be perfectly dry, and well corked to prevent the access of moisture. If the end of the tube or rod be rubbed, and afterwards brought into contact with a small ball of pith, or of any light con-

ducting matter, suspended by a silk thread, the excitement will be communicated to the ball, and if the communication be from the glass rod the electricity will be that denominated positive; if from the rod of sealing-wax or shellac, it will be what is called negative. Since the phenomena exhibited by balls charged negatively and positively are very nearly the same, it is not of much consequence which we call the positive or which the negative, provided we always apply the same name to the same kind of excitement. In the early discovery of the two kinds of electrical excitement, that which was produced by rubbing glass with a woollen cloth was called *vitreous*, and that from the friction of the same substance on sealing-wax or gum shellac was denominated *resinous*, and these terms are still retained, particularly in foreign works on the subject.

The simplest instrument for exhibiting the attraction and repulsion of electrified bodies, and determining the intensity and character of the excitement, is the gold leaf electrometer, or electroscope, which any person with a little patience and some mechanical skill may construct for himself. Different forms of this instrument are exhibited in Figures 2, 3, and 8.

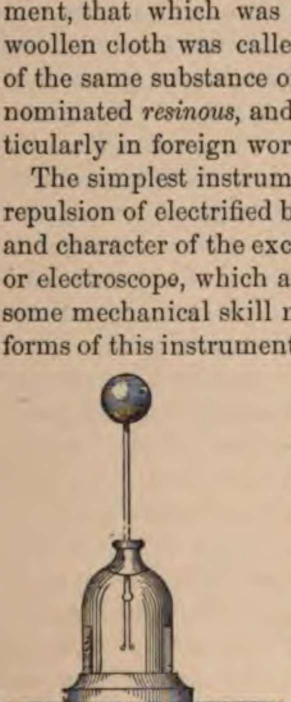

Fig. 2.

A brass wire, surmounted by a ball of the same metal, is passed through the cork of a small glass jar, or a large-sized vial, from which the bottom has been removed and its place supplied by a disc of wood; and to the lower end of the wire, which may be slightly flattened, is attached, by means of any adhering substance, two narrow strips of gold leaf so as to hang freely, and when un-excited parallel to each other without touching. Two small pith balls suspended close together by threads a few inches in length may be employed, in place of the gold-leaf strips.

When we wish to ascertain if a body is electrified, or whether different parts of it are charged positively to the

same degree for example, we bring in contact with the part to be examined a small metallic ball suspended at the end of a very fine silk thread, (a fibre from a cocoon will serve for this purpose,) and afterwards bring the small ball, which may be called the carrier, in contact with the ball, or as it is called, the knob of the electroscope. The electricity of the carrier will distribute itself, on account of the repulsion of its atoms, throughout the knob, the stem, and the leaves of the electroscope. The leaves being the only movable part will diverge from each other, and will thus exhibit the electrical repulsion to the eye. We see from this experiment, as well as from that of the ball touched with the excited glass, that electricity may be transferred from one body to another, and that when it is applied to the end of an elongated metallic conductor it instantly diffuses itself over the whole mass. In the experiment we have just described, the body was supposed to have been *positively* electrified; but a similar effect would have been produced had it been negatively charged. In that case, a portion of the natural electricity of the carrying ball would have been drawn from it by the un-saturated matter of the electrified body, and the ball in turn, when brought in contact with the upper end of the electroscope, would draw from it a portion of its natural electricity—the deficiency extending to the leaves—which would therefore diverge, since according to the theory unsaturated matter repels un-saturated matter.

If we wish to ascertain whether a body is electrified negatively or positively, we transfer a portion of its charge to the electroscope by means of the carrying ball, and then, having rubbed a rod of glass with a piece of woollen cloth, we bring it near to the electroscope; if the leaves diverge farther when the rod of glass is brought near, the original charge is of positive or *plus* electricity; if on the contrary the leaves converge, we may consider the electricity as negative or *minus;* or the same conclusion may be arrived at by rubbing a stick of sealing-wax with the woollen cloth, which becoming negatively excited will cause the leaves in the case of a positive charge to converge, and in that of a negative charge to diverge.

Conduction and Insulation of Electricity.—By means of a simple electroscope of the kind we have just described we may at once determine whether a body is a conductor or non-conductor of electricity. If a slight charge be given to the electroscope, (which may be effected by touching the knob with a rod which has been rubbed by woollen cloth,) the charge will remain with but little diminution for several hours, provided the air is perfectly dry; while if the air is moist, the charge is soon dissipated. These facts show that the former is a non-conductor, and the latter a partial conductor. Dry air would be a perfect insulator of electricity, provided it were motionless; the atoms which impinge against a charged body however become electrified with the same kind of excitement, and are consequently repelled, their place being supplied by others and so on until the charge is gradually diminished and finally dissipated.

If, when the electrometer is charged in dry air, we touch the knob with a glass rod, the leaves will be but little affected; but if we breathe on the surface of the rod, the glass will become a partial conductor and the leaves will slowly converge. If the ball be touched with one end of a metallic wire, the electricity will instantly be conducted off. If we make a similar experiment with a piece of dry wood, the charge will be gradually dissipated, a fact which indicates that wood is a partial conductor. By increasing the length of an imperfect conductor we shall find that the time of drawing off the charge is increased, and in this way it may be shown that there are very few bodies which are perfect conductors or non-conductors; that every body offers some resistance to the passage of an electrical current, provided we increase the length sufficiently to make it perceptible. By experimenting on various bodies in the way we have described, we may form an approximate table of the degrees in which different substances are conductors or non-conductors of electricity. The human body is a very perfect conductor of ordinary electricity, since if we touch the knob of the electroscope with the finger, the leaves instantly collapse, provided we are standing on the ground at the time. If

however we place a non-conductor (for example a cake of bees-wax) under the feet, the whole of the charge will probably not be withdrawn but shared with the body, and the leaves will only partially converge. It may also be shown by the same instrument that in order to produce electrical excitement by friction, it is only necessary that two dissimilar substances be rubbed together, one at least of which must be a partial conductor. For example, if while a person is standing on a cake of bees-wax he place one finger on the knob of an electroscope and another person strike him on the back with a silk handkerchief, the leaves will instantly diverge, showing that the whole body has received a charge of electricity, which is prevented from escaping into the floor by the interposed non-conducting bees-wax.

After the introduction of furnaces for heating rooms by warm air, the public was surprised at exhibitions of electrical excitement which previously had not been generally observed. If our shoes be very dry and we move over the surface of the carpet with a shuffling motion on a very cold day, (particularly in a room heated by a furnace,) the friction will charge the body to such a degree that a spark may be drawn from the finger, and under favorable circumstances a jet of gas from a burner may be thus ignited. There is nothing new or wonderful in this experiment; it is simply an exhibition of the production of electricity by friction, which only requires the carpet, the shoes, and the air to be dry, conditions most perfectly fulfilled on a day in which the moisture of the air has been precipitated by external cold and its dryness increased by its passage through the flues of the furnace. In the ordinary state of the atmosphere, the electricity which is evolved by friction is dissipated as rapidly as it is developed, but in very cold weather the non-conducting or insulating power of the air is so much increased that the electricity which is excited by the almost constant rubbing of bodies on each other, is rendered perceptible. Every person is familiar with the fact that on removing clothes, or shaking garments in cold dry weather, the electricity evolved by the rubbing exhibits itself in sparks and flashes of light.

The popular idea in regard to this is that the atmosphere at such times contains more electricity than at others; but these appearances are not due to the variation of the electricity in the atmosphere, but simply to the less amount of vapor which is present. When the clothes are rubbed together one part becomes positive and the other negative, and in dry air the excitement increases to such an intensity that the restoration of the equilibrium takes place by a visible spark; but when the air is moist, the equilibrium is silently restored as soon as it is disturbed, and no excitation is perceptible.

Similar effects are observed on the dry plains of the western part of our continent: in rubbing the horses or mules, sparks of electricity may be drawn from every part of the body of the animal. Persons in delicate health, whose perspiration is feebly exhaled, sometimes exhibit electrical excitement in a degree sufficient to surprise those who are not familiar with the phenomena. But these exhibitions have no connection with animal electricity, and are merely simple illustrations of the electricity developed by friction in an atmosphere too dry to permit the usual immediate and silent restoration of the electrical equilibrium.

Distribution of Electricity.—The mutual repulsion of the atoms of electricity, varying inversely as the square of the distance, gives rise to the distribution of the fluid in regular geometrical arrangements, the form of which may be calculated with mathematical precision. As one of the simplest cases of distribution, suppose a conductor of the form of a cylinder, with hemispherical ends (for example, one of wood, covered with tin foil) to be suspended horizontally in dry air with silk threads, and thus insulated to be slightly electrified by touching the middle of it with a charged body; the atoms of the fluid, by their mutual repulsion, will separate as far as possible from each other, and be found at the two extremities. If the conductor were not surrounded with a non-conducting fluid, like the air, they would be driven off by the same repulsion into space, and thus indefinitely separated.

This inference from the theory can readily be proved to be in accordance with the actual condition of the excitement, by bringing into contact with the middle of the length of the conductor a small carrier ball, and afterwards applying it to the knob of the electroscope. If the charge given to the conductor be small, scarcely any electricity will be found at the middle; if however the carrier be brought into contact with either end of the conductor, it will receive a charge of such intensity as to cause the leaves to diverge widely from each other. If a charge of electricity be imparted to the centre of a conductor in the form of a thin circular disc the fluid will be found, by a similar examination, in the greatest intensity, at the outer rim.

If we electrify a solid globe of metal, the excitement will be confined to an indefinitely thin stratum just at the surface of the conductor; for if the electricity be imparted to the centre of the globe along a wire through a glass tube, the electrical atoms will evidently separate from each other as far as possible, on account of their mutual repulsion, and would continue to diverge even beyond the surface, were it not that they were stopped by the non-conducting air which surrounds and insulates the globe. That this inference is true may be shown by an arrangement which is exhibited in Fig. 3, in which *A* represents a hollow metallic globe insulated on a glass pillar and charged with electricity. If the carrier ball *B* be let down into the interior of the globe, so as to touch the inner surface and then withdrawn without touching the side of the hole it will be found entirely free from electricity. If however it be made to

Fig. 3.

touch the outside of the globe, it will carry off with it a charge which will cause the leaves of the electroscope C to diverge in proportion to the original quantity imparted to the sphere. A similar effect will be exhibited if the ball B be lowered into an insulated cylinder of wire gauze A, Fig. 4, which has been charged with electricity. Not the least sign of excitement will be found on the inside, while a spark may perhaps be drawn from the exterior. The same result is produced, (as will be seen,) whether the globe be charged negatively or positively. On the hypothesis that the attraction and repulsion both observe the law of diminution with the square of the distance, this curious phenomenon is readily explained.

FIG. 4.

Newton has demonstrated the following propositions relative to the action of gravitation; and these principles are equally applicable to electrical attraction and repulsion, or to any other action which varies inversely as the square of the distance:

1. A particle of matter placed outside of a hollow sphere of attracting or repelling matter of uniform thickness, is acted upon as if all the matter were concentrated at the centre of the sphere.

2. A particle of matter (or of free electricity) placed at any point within a hollow sphere of uniform attracting or repelling matter, will be acted upon in every direction by an equal force, and will consequently be in equilibrium.

The form of the demonstration of the first of these propositions may be easily understood by a reference to Figure 5, and the accompanying considerations.

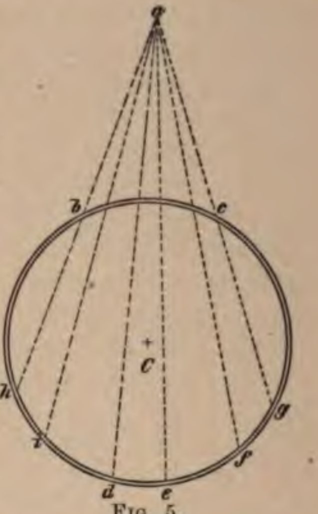

Fig. 5.

In this figure, *a* represents a particle of matter or of electricity attracted or repelled by the hollow sphere of which the centre is *C*. Let the two lines *a d* and *a e* represent the projection of a pyramid having its apex in *a*, and its base in *d e*, then it will be evident that the attraction of the three sections of the cone, one through the centre, another coinciding with the upper part of the spherical shell, and the third with the lower part included within *d e*, will be equal. For although the lower section is at a greater distance from *a* than the upper, yet its greater size just compensates for the greater distance, the surface increasing, as in the case of light, as the square of the distance, while the attraction and repulsion diminish in the same ratio. For the same reason, each of the two portions of the spherical shell are equal in action to a plate of equal thickness through the centre, included within the cone; and hence, the two together will be equal to a plate of double thickness at the centre.

If in the same way we suppose the whole spherical shell included in a series of pyramids or cones, having as a common apex the point *a*, and consider this series of cones made up of equi-angular pairs, the two members of which are on each side of the line through the centre as *h a i*, and *f a g*, then it will be clear that the resultant action of each of these pairs of cones will be in a line through the centre, and all the action of the sphere made up of such cones the same as if it were at this point.

That a point at the centre of a hollow sphere would be equally acted upon in all directions is evident; but that the same should be the case when the point is at *a*, Fig. 6, for example, is not quite so clear. It may however be rendered evident by considering the actions of the opposite bases of

the two cones *b a c* and *d a e*, or *f a g* and *h a i*, which (for a reason similar to that given in the preceding proposition) are respectively equal to each other; and as we may consider the whole interior surface of the spherical shell made up of the opposite bases of a series of pairs of similar cones, it is clear that the particle at *a* will be equally attracted or repelled on all sides, or in other words will be apparently un-affected by the action of the excitement which may exist at the surface.

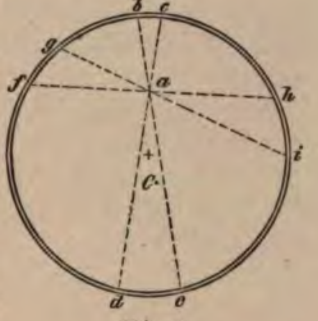

FIG. 6.

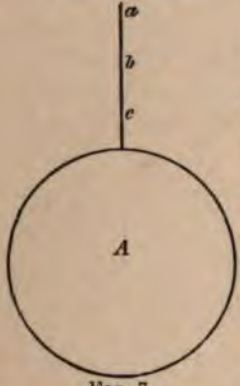

FIG. 7.

From the first of these propositions, it is easy to deduce the effect of a pointed rod in discharging the electricity from a globe. For if *A*, Fig. 7, be the centre of a charged sphere, from which the slender pointed conductor *a b c* projects, then will the action of all the electricity of the sphere on the point *a* be the same as if directed from the centre; and if we suppose for example that the sphere is charged with positive electricity, then will the atoms of electricity of the point *a* be repelled by all the atoms of the fluid of the globe, as if they were concentrated at *A*, and also the atoms of the fluid at the point *b*, below *a*, will be repelled by all the atoms of the electricity of the globe as if they were concentrated at the same point, and so on with the atoms at *c*, &c.; therefore the atoms at the point *a* will not only be directly repelled outward by the atoms of the fluid in the sphere, but they will also be pressed outward by the repulsion exerted on each of the atoms below, so that the whole force exerted to drive off the fluid from the point *a* will be in some relation to the number of atoms in the perpendicular column below this point; and hence the strong tendency to rupture the air and to escape, which must exist in a point projecting from a

charged surface; and for a similar reason, when the globe is charged negatively, to draw in electricity from surrounding bodies.

From the second proposition, we can readily deduce the fact of the distribution of the electricity at the surface; for if we communicate to the interior of a globe a quantity of electricity just sufficient to arrange itself in a stratum of the thickness of a single particle, it will so arrange itself on account of the mutual repulsion of the atoms, but if an additional quantity is thrown into the interior, it might not appear evident that this would also come to the surface, since the repulsion of the atoms already at the surface, (as it would seem at first sight,) would drive the additional atoms back towards the centre; but from the second proposition, the inner atoms are not affected by the outer, and consequently they would separate from each other by their mutual repulsion, as if the latter did not exist, and arrange themselves at the surface.

That this should take place when the sphere is charged with redundant electricity is not difficult to understand; but when a deficiency exists, the explanation has not been thought as easy. If however we suppose a quantity of the natural electricity drawn from the interior of a solid globe, then the un-saturated matter in the centre of the globe will act as a sphere, and draw into itself the electricity from around, and thus produce a hollow sphere of attracting matter, which will again draw into itself the natural electricity from around, and in this way, it must be evident, the deficiency will finally come to exist at the surface.

These propositions, which as we shall see are of great importance in the study of the theory of atmospheric electricity, can be readily demonstrated experimentally. If we coat a large hollow glass globe with tin foil, and insert through an opening into it a delicate electroscope, consisting of two slips of gold leaf suspended parallel to each other, (a small piece of the covering of tin foil being removed at two points on opposite sides to observe any effects produced within,) not

the slightest divergence will be seen in the gold leaves, when the globe outside is intensely charged with electricity. The same result will be obtained when a slip of gold leaf is suspended in the interior and electrified, either positively or negatively. It does not follow from these experiments that the electricity on the outside does not act on that of the inside. On the contrary, we must infer from the theory that every atom of electricity at the surface acts repulsively on every atom of electricity in the gold leaf; but these actions are equal in all directions, and therefore neutralize each other.

The second proposition may be demonstrated by means of a charged ball and the hollow globe, Fig. 3. If the charged ball, suspended by a silk thread, be placed at about eighteen inches above a gold leaf electroscope, and the divergence noted, and if then the ball be removed and its place occupied by the centre of the globe to which the electricity of the ball has been imparted, the divergence will be the same as before; or in other words, the action on the electroscope will be the same when a given quantity of electricity is concentrated on a ball at the centre of a sphere, or diffused throughout the surface of the same body. This experiment may be varied, with more striking results, by placing the hollow globe at a given distance from the electroscope, and then letting down a charged ball into its interior until it reaches the centre: the leaves will be seen to diverge to a definite degree; if the ball be now made to strike the interior surface of the globe, by moving the suspending thread of silk, the whole of the charge will pass to the surface of the latter, but the leaves will exhibit the same amount of divergence as before the transfer. The electricity which is distributed throughout the surface of the globe produces precisely the same effect as it did when confined to the ball at the centre.

The mathematical problem to be solved, for the purpose of calculating the distribution of a given charge of electricity in a body of any form, is to proportion the amount of the fluid in each part of the surface, so that the resultant action on the interior of a body will be completely neutralized. This problem, which is simple for the sphere, becomes

too complex, even for the highest powers of mathematics, for bodies of less regular forms than those generated by the revolution of simple curves.

Electrical Induction.—The attraction and repulsion of electricity, like those of magnetism, act at great distances, and produce phenomena which it is necessary clearly to understand in order properly to comprehend the explanation of many of the facts connected with atmospheric electricity.

For the exhibition of these phenomena, which are classified under the name of inductive effects, we may make use

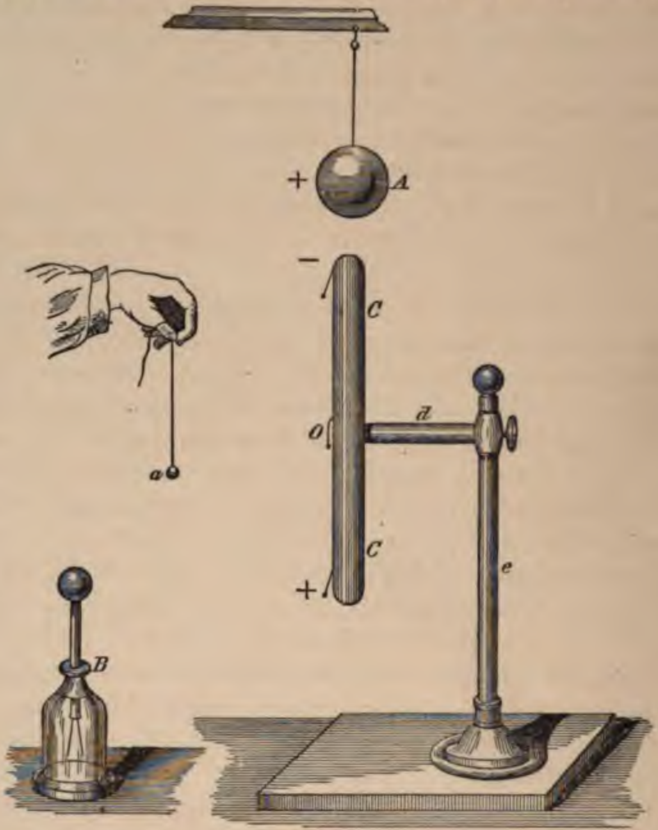

FIG. 8.

of the arrangement represented in Fig. 8, in which A is a metallic globe suspended in free air by a fine silk thread, and

thus insulated. O is a long cylindrical metallic conductor, supported by a rod of shellac or sealing-wax d, on stand e, having a glass stem.

Now each of these metallic bodies contains its natural share of electricity, and as long as this continues to be the same no electrical effects are exhibited; for although the natural electricity of A will repel the electricity of O, yet the matter of A will attract it with an equal force, and hence there will be no perceptible effect. Let us however suppose that there be imparted to the globe A a redundant quantity of electricity, then the equilibrium in the conductor O will be disturbed; the repulsion of the redundant fluid will be greater than the attraction of the un-saturated matter, and hence a portion of the natural electricity of O will be driven down to its lower end, and consequently the upper end will become negatively, while the lower is positively electrified. It must be evident therefore that between the two extremes there will be a point near the middle which will be in its ordinary condition.

These inferences may readily be shown to be true by observing three movable pith balls suspended by linen threads, one near the top, another at the middle, and the third at the lower end. Those at the extremities will diverge, exhibiting excitement, while the one at the middle will remain unmoved, indicating that this point is in a natural condition. To be assured that the upper end is negatively electrified, and the lower positively, it is only necessary to rub a stick of sealing-wax with woollen cloth, and bring it in succession near the two balls; the upper one will be repelled and the lower one attracted; or we may arrive at the same results by touching in succession the two extremities and the middle of the conductor with the small carrier ball a, and applying it to the knob of the electroscope B.

If the conductor O be removed laterally to a distance from under the charged globe, the excitement will disappear, the atoms of natural electricity, by their mutual repulsion at the lower end, and attraction for un-saturated matter at

the upper end of the conductor, will distribute themselves uniformly, and assume their natural condition. In this experiment the fact is illustrated that all bodies are naturally charged with electricity, which exhibits itself when the equilibrium is disturbed by the action of some extraneous force. If the conductor *O* be restored to its former position the excitement will be renewed, provided the globe *A* has lost none of its charge, and the two pith balls will diverge as before. If the charge of electricity in the insulated globe be increased, the repulsive action or induction, as it is called, will also be increased; another portion of electricity will be impelled down into the lower end, increasing the repulsive action at that point, and also the amount of attraction at the upper end. The middle of the conductor however will still remain in a condition of neutrality. Again, if while the charge in the globe *A* remains the same, the space between it and the upper end of the conductor is diminished, a greater excitement will be exhibited by the increased divergence of the balls at the two extremities; for since the force increases with a diminution of distance, an additional quantity of the natural electricity of the upper end will be driven down into the lower end, and an equal amount of un-saturated matter will be left at the upper end.

We may still further vary the experiment by lengthening the conductor *O*, the charge of the globe and its distance from the upper end remaining the same, and for this purpose the conductor may be made to draw out like the tube of a telescope. We shall find that the greater the length, the greater will be the intensity of the effect at each end. To understand this we have only to recollect that the atoms of electricity constantly repel each other, and that in the case of a short conductor, but little comparatively can be driven from the upper end, because the self-repulsion of the electricity of the lower end and the attraction of the un-saturated matter of the upper end both conspire to restore the distribution, but when we give a greater length to the conductor for the free electricity of the lower part to expand into, and thereby lessen the intensity of the repulsion and

also remove the free electricity farther from the centre of attraction of the redundant matter, the tendency to restore the normal condition is much lessened, and a new quantity will be repelled into the lower end from the upper, and thus produce at that end a greater intensity of excitement. If we increase indefinitely the length of the conductor, (or what amounts to the same thing) if we connect the lower end of it by means of a metallic wire or other conductor with the earth or elongate it till it touches the earth, then we shall have the maximum of effect. The neutral point will descend to the earth, while the conductor, thoughout its entire length, will be charged negatively.

The effects which we have described are those which would take place if we supposed the electricity in the globe suffered no change in its distribution on account of the induction; but this cannot be the case, since in the action of one body on another—an equal re-action must be produced, hence the un-saturated matter in *O* will re-act on the free electricity in the globe, and draw down into its lower side a portion of that which before existed in the upper side, and thus render the lower side more intensely redundant than before. This additional quantity of free electricity in the lower side will tend to increase the amount of un-saturated matter in the upper part of the conductor. The maximum effect will be produced, as we have before stated, when the lower end of the conductor is brought in contact with the earth, which may be considered as a conductor of infinite capacity. In this condition the self-repulsion of the atoms of the fluid in the lower part of the globe, and the attraction of the un-saturated matter in the upper end of the conductor, may become so great as to cause a rupture of the intervening air and a transfer of the redundant electricity in the form of a spark from the upper to the lower body.

If instead of the metallic conductor we substitute a rod of shellac or glass of the same length and diameter under the same conditions, no spark (or but a very feeble one) will be produced. The natural electricity cannot be driven down on account of the non-conducting character of the

material, and while it remains at the top it repels the free electricity of the globe as much as the matter of the globe attracts it. For a similar reason, if a small brass ball be placed on the top of a rod of glass and presented to the globe, but a feeble spark will be elicited; the inductive influence will act in this case under unfavorable conditions, a portion of the natural electricity, it is true, will be driven down into the lower surface of the ball, and an equal amount of un-saturated matter will exist at the upper surface; but the attractions and repulsions will be so nearly at the same distance that but a comparatively feeble effect will be produced. An attentive consideration of these facts is essential to a knowledge of atmospheric electricity, and necessary to understand and guard against the effects of the destructive discharges from the thunder-cloud.

The inductive action we have described takes place at a distance through an intervening stratum of air, but the same effect is produced, and with nearly the same intensity, when the intervening space is occupied with glass or any other non-conducting substance. If a disk of wood, which is a partial conductor, is interposed, the effect will be slightly modified, because an inductive action will take place in the substance of this which will tend to increase the effect in the conductor *O*, below.

As an illustration of the inductive influence of free electricity at a distance on the natural electricity of a conductor, we shall direct the attention of the reader to an arrangement exhibited in Figure 9, which is that of an experiment made by the author in Princeton, in 1842*. Two circular disks of wood, *a* and *b*, each about 4 feet in diameter, were entirely covered with tin foil; one was in connection with a large insulated conductor of an electrical machine in the upper story of a building, the other was supported on a glass foot in the lowest story, at the distance of about 25 feet below, with two floors and ceilings intervening. The upper disk being charged by the machine, the lower one was touched with the finger, so as to suffer the in-

* [Proceedings Am. Phil. Society, June 17, 1842. See *ante*, vol. I, p. 203.]

duced electricity to escape into the ground. If when in this condition the knuckle was held near the lower disc and the upper one suddenly discharged by a spark received on a ball attached to the end of a wire connected with the earth, a spark was seen to pass between the knuckle and the lower disk. A similar effect was produced when the upper plate was suddenly charged by powerful sparks from the machine, though the intensity in this case was somewhat less.

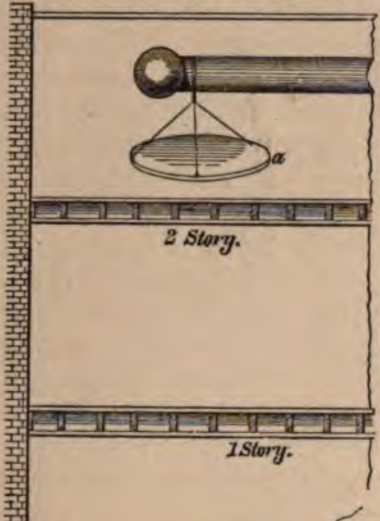

FIG. 9.

In this experiment, the upper disk may represent a charged thunder-cloud, and the lower one the ground, or any conducting body within a house. While the charged cloud is passing over the building, all conducting bodies in it, by this inductive action at a distance, have their natural electrical equilibrium disturbed; the upper part of each body becoming negatively electrified, and the lower part positively; and if the cloud continue in this position for a few minutes, the free electricity of the lower part of the conductor will be gradually driven into the earth, through the imperfect insulation of the floor. If in this case the lower part of the cloud is suddenly discharged, sparks of electricity may be perceived, and perhaps shocks experienced, by the inmates of the dwelling, produced by the sudden restoration of the equilibrium, due to the removal of the repulsive force of the cloud on the natural electricity of the bodies below.

The inductive action of the electrical discharge at a dis-

tance is still more surprisingly exhibited, by an arrangement shown in Figure 10, which the writer adopted about the same time during his electrical investigations at Princeton.

The roof of the house which he occupied in the college campus was covered with tinned iron, and this covering was therefore in the condition of an insulated plate, on account of the imperfect conduction of the wood and brick-work which intervened between it and the ground. To one of the lower edges of this covering was soldered a copper wire, which was continued downward to the first story, passed through a gimlet-hole in the window-frame into

FIG. 10.

the interior of the author's study, and then passed out of the lower side of the same window, and thence into a well, in which it terminated in a metallic plate below the surface of the water. Within the study, the wire was cut and the two ends thus formed were joined by a spiral of finer wire *a* covered with silk thread. Into the axis of this spiral a large sized sewing-needle *d* was inserted, the point having been previously attached to a cork, which served as a handle for removing it. With this arrangement, the needle was found to become magnetic whenever a flash of lightning was perceived, though it might be at the distance of several miles. The intensity of magnetism and the direction of the current were ascertained by presenting the end of the needle to a small compass represented by *c*. In several instances the inductive action took place at such a distance, that after seeing the flash the needle was removed its magnetic con-

dition observed and another needle put in its place, before the noise of the thunder reached the ear. In this experiment the inductive action of the electrical discharge in the heavens was exerted on the natural electricity of the tinned roof, (a surface of 1,600 square feet,) and a considerable portion of this passed down through the wire into the well. The arrangement served to indicate an action which would otherwise have been too feeble to produce a sensible impression.

It must be observed that the effect here described was not produced by the actual transfer of any electricity from the cloud, but was simply the result of induction at a distance and would probably have been nearly the same had the intervening space been filled with glass or any other solid non-conducting substance. We say probably very nearly the same, because Professor Faraday has shown that the inductive effect at a distance is modified by a change in the intervening medium.

It is also proper to mention here, (although we cannot stop to give the full explanation of the means by which the result was obtained,) that the electricity passing along the wire was not that due to a single discharge into the well, but to a series of oscillations up and down in alternate directions until the equilibrium was restored.

Electricity in Motion.—The phenomena we have thus far described relate principally to electricity at rest. Those which relate to ordinary or frictional electricity in motion have not been so minutely investigated as the other class, and present much more difficulty in ascertaining the laws to which they are subjected. The discharge of electricity from the clouds or from an ordinary electrical machine is so instantaneous that we are principally confined in our investigations to the effects which remain along its path after its transfer.

The electricity however which is developed by chemical action in a galvanic battery is of sufficient quantity to produce a continuous stream, or at least a series of impulses in such rapid succession that they may be considered continuous. By employing electricity of this kind, it has been supposed

that we can study the fluid while it is actually in motion, and from the results deduce inferences as to the mode in which some of the effects are produced in the discharge of frictional electricity. The two classes of phenomena however, though referable to the same cause, are in many respects so different in character that considerable caution is required in drawing inferences from analogy. The phenomena of ordinary electricity are characterized by an intensity of action which indicates a repulsive force between the atoms of the hypothetical fluid, which is in some way—at least partially neutralized, in the case of galvanism.

Ordinary electricity in a state of equilibrium appears to produce but a very feeble effect upon bodies in which it is accumulated. However great may be the quantity present, no effect is perceived by a person when insulated on a glass stool, and charged either positively or negatively, so long as the electricity remains at rest. If however it is drawn from him in the form of a spark, then a disagreeable pricking sensation is experienced at the point of rupture. Dr. Faraday constructed a small metallic house or room, which he suspended by silk ropes in mid air, and charged it so strongly that long sparks could be drawn from the outside, yet not the least effect was perceived by the persons within: even when the air of the interior of the house was strongly electrified, the excitement was only perceptible on the outside.

It is fully established by the most satisfactory experiments that in all cases in which a discharge of electricity takes place by breaking through a stratum of non-conducting subtance like air, there is an actual transfer of matter each way between the two ends or sides of the opening in the conductor along the path which the spark traverses. If two conducting rods be employed having the end of each terminated by a brass ball, one of which is covered with gold leaf, and the other with silver, a transfer in opposite directions of these two metals will be observed. A similar effect is produced in the discharge of lightning from the clouds, and there are several well authenticated cases on record, in

which a picture as it were of one body has been impressed on another between which the electrical discharge took place.

Another effect produced by the discharge, and having an important bearing upon the explanation of some of the mechanical results of electricity, is a sudden and violent repulsive energy given to the atoms of air and other substances through which it passes, and which causes them to separate with an explosive violence.

This may be shown by transmitting a discharge from an electrical battery between two brass balls projecting into the inside of a glass bulb, to the lower side of which is joined an air-tight tube containing a small quantity of water, and opening at the end into a cup of water, the arrangement with the exception of the balls being similar to that of an air thermometer. The moment the discharge takes place, the water will be driven down the tube, exhibiting a great enlargement of the volume of air in the bulb. This experiment was communicated by Mr. Kinnersley, of Philadelphia, to Dr. Franklin. The effect at first was attributed to heat produced by the discharge of electricity through the air in the bulb, but although there *is* heat evolved in this case, (as is proved by the fact that if a number of sparks be passed in succession the water does not return to its first altitude, and thus indicates an increase of temperature,) yet the principal cause is evidently the sudden repulsive energy given to the air at the moment of the passage of the discharge, as may readily be shown by inclosing a thermometer within the bulb. The increase of temperature which this indicates will be far too small to account for the great and sudden expansion produced. A similar exhibition of force is exhibited when a strong discharge of electricity is passed through a vessel (like the one we have described) filled with water. In this arrangement a thick glass bulb may be broken into pieces.

The mechanical effects produced by lightning must be attributed principally to this cause. When a powerful discharge from a cloud passes through a confined space filled with air, and surrounded by partial non-conductors, a tre-

mendous energy is exerted. In the case of a house examined by the writer, the discharge fell upon the top of a chimney at the west end of the building and passing through a stove-pipe hole traversed the space under the rafters, (called the cock-loft), to the chimney at the east end and thence down to the ground; the force exerted was sufficiently great to lift up the whole roof from the top of the walls on which it rested. In like manner, when the discharge takes place along the upright timbers of a house, the clap-boards are frequently blown off outward and the plaster inward as if by the explosion of gunpowder.

To a similar action we must ascribe the splintering of trees by lightning. At the moment of the passage of the discharge the sap or moisture is suddenly endowed with a repulsive energy which resembles in its effects the action of an explosive compound, separating the fibres longitudinally and projecting parts of the body of the tree to a distance. When a tree is struck by lightning the greatest effect is usually produced on the main stem just below the branches. A portion of the discharge appears to be received on each twig, leaf, and branch, and the whole concentrated by converging towards the trunk. The repulsion imparted to the atoms of a conductor is in some cases sufficiently great to at once dissipate in vapor fine metallic wires, and this so instantaneously that the silk covering by which they are surrounded for telegraphic purposes is not burned.

The repulsive energy is exerted not alone laterally, but perhaps in a greater degree in the line of direction of the conductor, tending to separate it as it were by transverse sections. Hence when electricity passes through a wall into the interior of a house, a pyramidal mass of plaster is thrown out. A similar effect is frequently produced when the discharge takes place between the cloud and the level earth: a large conical or pyramidal hole is formed, from which the earth is thrown out as if by the explosion of a quantity of powder beneath the surface. Such excavations are supposed by some to indicate a discharge of electricity from the earth to the cloud, but no conclusion of this kind can, with

certainty, be drawn from the phenomena. It simply indicates an intense repulsive energy exerted between the atoms of matter in the line of discharge. It sometimes happens when an old tree which has perhaps been moistened by the rain—is struck by lightning, instead of being rent laterally it is broken off transversely, the upper part being projected vertically upward. This effect however is not usually produced, since the force exerted by the tree to resist transverse breaking is much greater than that to prevent lateral tearing apart.

In the passage of electricity from a charged conductor, or from a cloud to the earth, it always follows the line of least resistance and by an antecedent induction determines the course it is to pursue. This is strikingly exhibited by an experiment devised by Sir W. S. Harris. A number of separate pieces of gold leaf are attached to a sheet of paper. If a discharge sufficiently strong to dissipate the gold and blacken the paper be passed through them, its course will be shown by the blackened parts; and it is especially worthy of remark, that not only are the pieces out of the line of least resistance untouched, but even portions of other pieces are left unchanged from the same cause. Now these separate pieces of gold leaf may be taken to represent detached conductors fortuitously placed in the construction of a building.

The apparently fitful course of a discharge in its passage through a building frequently excites surprise, leaping (as the electricity does) from one conductor to another, and sometimes descending to the earth in several streams; but that the discharge should leap from one conductor to another through a considerable intervening space of air is not surprising, since its original intensity was sufficient to enable it to break through a stratum of the atmosphere of perhaps a mile in thickness before it reached the house.

Whenever electricity passes through an interrupted conductor so as to exhibit the appearance of light, a great increase of intensity is always manifested at the point of disruption, as if the charge halted here for a moment until a

sufficient quantity of the fluid could accumulate to force its passage through the obstacle. An illustration of this action is presented in the fact, that at the point where the lightning leaves a conductor, and also where it is received by another conductor, signs of fusion or of more intense action are always exhibited. An effect of lightning described by Professor Olmsted, at a meeting of the American Association, in New Haven, may be explained on this principle. A row of five or six milk-pans, placed in the open air on a bench, was struck by a discharge from a cloud. The electricity passed through the whole series, making two holes in each pan, at opposite extremities of the diameter, or at the places where the electricity may be supposed to have entered and gone out.

There is another circumstance connected with the discharge of electricity—having an important bearing on the construction of lightning-rods, which may be mentioned in this place. When the repulsion of the atoms of electricity in a conductor or in a cloud and the attraction of the unsaturated matter below become so intense as to cause a rupture in the air, the electricity of the cloud is precipitated upon the conductor, and not only restores the natural quantity, but also gives it for a moment a redundancy of electricity, a fact which must be evident from the theory, when we consider the distance at which the induction is communicated. As this charge of free electricity passes down the rod to the earth, for example, it assumes the character of a wave, rendering the metal negative in advance; and thus in the transmission of free electricity through a rod of metal, the action consists of two waves, one of redundancy, immediately preceded by one of deficiency. Hence if a small ball connected with the earth by a wire be brought near a conductor (for example a lightning-rod) on the upper end of which, discharges of electricity are thrown from an electrical machine, sparks may be drawn from the rod, however intimately it may be connected with the earth below.

This effect was strikingly exhibited by an experiment

made by the author, which consisted in placing one end of a copper wire (a tenth of an inch in diameter) beneath the water of a well, its upper end being terminated by a small ball, and throwing on it sparks of electricity from a globe of a foot in diameter. Although in this case the conductor was as perfect as possible, yet sparks sufficiently intense to explode the oxy-hydrogen pistol were obtained from the wire throughout its whole length.

This effect was not due, as some have supposed, to the tendency of the electricity to seek another passage to the earth, as may be shown by catching the spark in a Leyden jar; but it was solely the effect of a transient charge of electricity passing along the surface of a conductor from one extremity to the other.

The phenomena may be expressed generally by the statement that when electricity is thrown explosively as it were, on the end of an insulated conductor, by a disruptive discharge through the air, it does not pass silently to the earth, but tends in part to be given off in sparks to all surrounding bodies. It is on this account that we object to the otherwise admirable arrangement of Sir W. Snow Harris for the protection of ships from lightning. Though the main portion of the discharge of electricity is transmitted innoxiously to the ocean by means of the slips of copper which are carried down along the mast and through the bottom of the vessel to the sheathing beneath, as proposed by him, yet we consider it safer to conduct it across the deck and over the sides of the vessel to the copper sheathing. It is true, the quantity which tends to fly off laterally from the rod is small, yet we have shown by direct experiment that it is sufficient even when produced by the electricity of a small machine, to set fire to combustible materials; and therefore it cannot be entirely free from danger in a ship, loaded for example with cotton.

The atoms of electricity, in their transfer from one body to another, still retain their repulsive energy; and if the discharge be not very large in proportion to the size of the conductor, it will be principally transmitted at the surface.

If the charge be very large, and the conductor small, it will probably pervade the whole capacity, and as we have seen, in some cases, will convert into an impalpable powder or vapor the solid particles. Because electricity in a state of rest is found distributed at the surface of a body, it was immediately assumed without examination, that electricity in motion passes along the surface; but this conclusion was supposed to be dis-proved by the fact that the conducting power of a wire for galvanic electricity is in proportion to the area of the cross-section, from which it follows that this kind of electricity pervades the whole mass of the conductor. But galvanic electricity differs from common electricity, apparently in the exertion of a much less energetic repulsion, and in a greater quantity developed in a given time. The deduction therefore from the experiments with galvanism can scarcely be considered as conclusive in regard to frictional electricity.

To settle this point, the writer devised a series of experiments which fully proved the tendency of electricity of high tension, (that is of great repulsive energy,) to pass along the surface. It will be sufficient to give as an illustration of this fact, the result obtained by the arrangement represented in Fig. 11, in which *C D* is a copper wire, (one of the best

Fig. 11.

conductors of electricity,) of the size usually employed for ringing door-bells, passing through the axis of an iron tube, or a piece of gas-pipe, *A B*, about three feet long. The middle of this wire was surrounded with silk, and coiled into a magnetizing spiral, into which a large sewing-needle was inserted. The wire was supported in the middle of the tube by passing it through a cork (covered with tin-foil), at each end, *h i*, so as to form a good metallic connection between the copper and the iron. Two

other magnetizing spirals of iron wire, *f* and *y*, were arranged on opposite sides of the tube, the ends soldered to the iron. When these two spirals were also furnished with needles, and a discharge from a Leyden jar sent through the apparatus, as if to pass along the wire, the needle inside of the iron tube was found to exhibit no signs of magnetism, while those on the outside presented strong polarity. This result conclusively shows that notwithstanding the interior copper wire of this compound conductor was composed of a material which offered less resistance to the passage of the charge than the iron of which the outer portion was formed, yet when it arrived at the tin-foil covering of the cork, it diverged to the surface of the tube, and still further diverged into the iron wire forming the outer spirals. We must not however conclude from this experiment that the electricity actually passed on the outside of the tube. On the contrary, we must infer from the following fact that it passes just within the surface. If the iron be coated with a thin covering of sealing-wax, the latter will not be disturbed when a moderate discharge is passed through it, though with a large discharge in proportion to the conducting power of the rod, the outward pressure may become so great as to throw off the stratum of sealing-wax. This point is of some importance in regard to the question of painting lightning-rods. If the metal is of sufficient size to freely transmit an ordinary discharge from the clouds, the condition of the exterior surface can have but little effect, and we see no objection to coating it with black paint, the basis of which is carbon, a good conducting material.

It is also to the same repulsive energy that we may attribute the spreading of a discharge when it passes through partial conductors, as in the case in which a spark from an electrical machine is transmitted over a pane of glass on which particles of iron filings are sparsely scattered. It is probable that drops of rain and partially condensed vapor in the atmosphere are in some cases connected with a similar appearance of discharge of electricity in the heavens.

A much longer spark of electricity can be drawn through

rarified air than through that of ordinary density. The light which accompanies a discharge in this case assumes different colors, the violet predominating. This is a fact of interest in connection with the color exhibited by lightning, and we may infer that the discharges of a violet hue take place between clouds at a great elevation in the atmosphere.

The electric spark, when passed through a confined portion of atmospheric air, is found to produce a chemical combination of its component parts, namely nitrogen and oxygen, and to form nitric acid. The same result is produced on a grand scale in the heavens during thunder-storms; hence the rain water that falls, (in the summer season especially,) always contains a considerable quantity of nitric acid, which is considered by the chemist as furnishing a portion of the nitrogen essential to the growth and development of the plant: and to the same source is referred the nitric acid in the nitrate of lime and potash found in the form of efflorescence on damp ground and the walls of old buildings. Indeed, all the nitrate of potash from which gunpowder is manufactured is supposed to have its origin in this way, and the explosion from the thunder-cloud and that from the cannon, may be looked on as in one sense—the counterparts of each other.

Again, during the transmission of electricity from an ordinary electrical machine a pungent odor is perceived, something analogous to that produced by the slow combustion of phosphorous, which Professor Schönbein, by a long-continued series of researches, has shown to result from a change in the oxygen of the air. He supposes that this substance is composed of two atoms, which by their combination partly neutralize each other, but which are separated by the repulsion of the electric spark, and when thus set free —have a much greater tendency to combine with other substances than in their ordinary state of union. Oxygen thus changed or dissociated is called ozone, and as it would appear, performs an important part in many of the molecular and chemical phenomena of the atmosphere. To this increased combining power of oxygen may be attributed the

formation of the nitric acid we have mentioned, and without such an explanation, it would be difficult to conceive how particles of oxygen and nitrogen, which are rendered mutually repulsive by the electrical discharge, should enter into chemical combination.

We have seen that though metals are generally good conductors, yet when electricity falls upon a rod of iron or copper explosively, the energetic repulsion, which must always accompany these explosions, tends to throw the particles off on all sides, and when the discharge is sufficiently great the conductor itself is dissipated in vapor. Water is a much inferior conductor to iron, and though a large mass of it will silently discharge a conductor, yet it offers great resistance to the transmission of electricity explosively, and hence the electricity is sometimes seen to leave a conductor, and pass a considerable distance over the surface of water, rather than to force its passage through the interior of the mass. It is therefore highly important in arranging lightning rods that they should be connected at the lower end with a large surface of conducting matter, to prevent as far as possible the fluid from leaving the rod in the case of an explosive discharge.

Electricity of the Atmosphere.

Having given in the preceding sections a brief exposition of the general principles of electricity, we are now prepared to apply these to an exposition of the phenomena of atmospheric electricity.

The origin of the electricity of the atmosphere has long occupied the attention of physicists, and at different times they have apparently settled down on some plausible hypothesis which merely offered a probable explanation of the phenomena without leading to new facts or pointing out new lines of research.

The earth, as is now well known, is an excellent conductor for the most feeble currents of electricity, provided the contact with it of the electrified body be sufficiently broad. The aerial covering which surrounds it, is however

a non-conductor, and is capable of confining electricity in a condition of accumulation or of diminution, and of preventing the restoration of the equilibrium that without the existence of this insulator, would otherwise take place.

The hypothesis was at first advanced that the earth attracts the ætherial medium of celestial space and condenses it in a hollow stratum around the whole globe; that the electricity of the atmosphere is due to the action of this exterior envelope. Dr. Hare, our countryman, has presented this hypothesis with considerable distinctness. Without denying the possibility or even probability of such a distribution of electrical excitement, we may observe that if this electrical shell were of uniform thickness, and we see no reason to suppose it should vary in different parts in this respect, it would follow from the law of central forces, that it could have no effect in disturbing the equilibrium on the surface or in the interior of the earth; a particle of matter remaining, as we have seen, at rest or un-affected at any point within a hollow sphere. This fact appears to militate against the truth of this assumption.

Another hypothesis attributed the electricity of the atmosphere to the friction of the winds on each other and on the surface of the earth, but careful experiments have shown that the friction of dry air on air, or of air on solids or liquids does not develop electrical phenomena.

The next hypothesis—advanced by Pouillet, referred the electricity of the atmosphere to the evaporation of water, particularly that containing saline ingredients. But when pure water is carefully evaporated in a space not exposed to the sky, no electricity is produced except by the friction with the sides of the vessel in the act of rapid ebullition; and when the experiment is made with salt water the electrical effects observed are found to be produced by an analogous friction of the salt against the interior of the vessel. When pure water is evaporated under a clear sky the vapor produced is negatively electrified; but this state is contrary to that in which the atmosphere is habitually found.

Pouillet also supposed that the process of vegetation was a source of disturbance of the electrical equilibrium, but this has not been supported by critical experiments.

The discovery accidentally made a few years ago of the great amount of electricity evolved in blowing off steam from the boiler of a locomotive, seemed to afford a ready explanation of the electrical state of the atmosphere. It was then attributed to the condensation of the aerial vapor. Faraday proved however by one of his admirable series of model experiments, that this effect was due entirely to the friction of the water (which escaped in connection with the steam) on the side of the orifice through which the discharge took place. When dry steam, or that which is so heated as to contain no liquid water, was blown out, all electrical excitement disappeared; and when condensed air —even at elevated temperatures, was discharged from an insulated fountain, no electricity was produced.

The celebrated physicist of Geneva, Professor De la Rive, refers the electricity of the atmosphere to thermal action. It is well known that if the lower end of a bar of iron (or of any other metal not readily melted) be plunged into a source of heat while the upper end remains cool, a current of electricity will flow from the heated to the cooled end, the former becoming negative and the latter positive, and that these different states will continue as long as the difference of temperature is maintained. Now according to Professor De la Rive a column of the air is in the same condition as the bar of metal—its lower end is constantly heated by the earth and its upper cooled by the low temperature of celestial space. Unfortunately however for this ingenious hypothesis, a column of air is a non-conductor of electricity, while a bar of metal is a good conductor, and it still remains to be proved that such a distribution of electricity as that we have described relative to the bar of metal can be produced in a column of air.

The foregoing are the principal hypotheses which have been advanced to account for what has been considered the free electricity of the atmosphere. After an attentive study

of the whole subject, we have been obliged to reject them all as insufficient, and compelled in the present state of science to adopt the only conclusion which appears to offer a logical explanation of all the phenomena, namely that of Peltier, which refers them not to the excitement of the air, but to the inductive action of the earth primarily electrified.

The author of this theory we are sorry to say did not receive that attention which his merits demanded, nor his theory that consideration to which so logical and so fruitful a generalization was justly entitled. Arago, in his great work on the phenomena of atmospheric electricity, does not allude to the labors of Peltier; the reason of which may be that his work was not intended as a scientific exposition of the principles of the phenomena, but merely a collection and classification of observed facts.

Peltier commenced the cultivation of science late in life and since the untutored mind of the individual, like that of the race, passes through a series of obscure and complex imaginings before it arrives at clear and definite conceptions of truth, it is not surprising that his first publications were of a character to command little attention, or rather to excite prejudice on account of their apparently indefinite character and their want of conformity with established principles. His theory of atmospheric electricity requires to be translated into the ordinary language of science before it can be readily comprehended even by those best acquainted with the subject, and hence his want of appreciation may be attributed more to the peculiarities of the individual than to the fault of the directors of science in France.

According to the theory of Peltier, the electrical phenomena of the atmosphere are entirely due to the induction of the earth, which is constantly negative or what in the theory of Du Fay is called resinous. He offers no explanation (so far as we know) of this condition of the earth, which at first sight would appear startling, but on a little reflection is not found wanting in analogy to support it. The earth is a great magnet, and possesses magnetic polarity in some respects similar to that which is exhibited in the case of

an ordinary loadstone or artificial magnet. This magnetism is of an unstable character however, and is subjected to variations in the intensity and in the direction of its polar force. In like manner we may consider the earth as an immense prime conductor negatively charged with electricity, though its condition in this respect may—like that of its magnetical state—be subject to local variations of intensity, and perhaps to general as well as partial disturbance.

It may be said that this merely removes the difficulty of the origin of the electricity of the atmosphere to an un-explained cosmical condition of the earth; but even this must be considered an important step in the progress of scientific investigation. The hypothesis of Peltier has since his death been rendered still more probable by the labors of Sabin, Lloyd, Lamont, Bache, and others, in regard to certain perturbations of the magnetism of the earth, which are clearly referable to the sun and the moon. It must now be admitted that magnetism is not confined to our earth, but is common to other—and probably to all the bodies of our system; and from analogy we may also infer that electricity, a coordinate principle, is also cosmical in its presence and the extent of its operation. That the earth is negatively electrified was proved by Volta at the close of the last century. For this purpose he received the spray from a cascade on the balls of a sensitive electroscope; the leaves diverged with negative electricity.

This experiment has been repeated in various parts of the globe, and always with the same result. That it indicates the negative condition of the earth is evident, when we reflect that the upper level from which the water falls must be considered as the exterior of the charged globe, and hence must be more intensely electrified than points nearer the centre. Since the earth is (as a whole) a good conductor of electricity, as shown by the operations of the telegraph, the electrical tension of it cannot differ much in different parts, and we are at present un-acquainted with any chemical, thermal, or mechanical action on land of sufficient magnitude to produce this constant electrical state. We are there-

fore induced to adopt the conclusion that the earth—in relation to space around it, is permanently electrical; that perhaps the ætherial medium, which has been assumed as the basis of electricity, as was supposed by Newton, becomes rarer in the vicinity of—and within bodies of ponderable matter. Be this as it may, all the phenomena observed in the atmosphere, and which have so long perplexed the physicist, can be apparently reduced to order, and their dependencies and associations readily understood, in accordance with the foregoing assumption. This is not a mere vague supposition, serving to explain in a loose way certain phenomena, but one that enables us not only to group at once a large class of facts, (which from any other point of view, would appear to have no connection with each other,) but also to devise means for estimating the relative intensity of action, and to predict both in mode and measure changes of atmospheric electricity before they occur. It follows, as a logical consequence from this theory, that salient points, such as the tops of mountains, trees, spires, and even vapors, if of conducting materials, will be more highly excited than the general surface of the globe, in a manner precisely similar to the more intense excitement of electricity at the summit of a point projecting from the surface of the prime conductor of an ordinary electrical machine.

It also follows from the same principle that if a long metallic conductor be insulated in the atmosphere, its lower end, next the earth, will be positive, and the upper end negative. The natural electricity will be drawn down by the unsaturated matter of the earth into the lower end of the wire, which will there become redundant, while the upper end will be rendered negative or under-saturated. That this condition really takes place in the atmosphere was proved in a striking manner by the experiment of Gay-Lussac and Biot in their celebrated aerial voyage, which consisted in lowering from the balloon an insulated copper wire, terminated at each end by a small ball. The upper end of this was found to be negative, and consequently the lower end must have been positive, since the whole apparatus—includ-

ing the balloon—was insulated. The experiments should be repeated at different elevations by some of our modern aeronauts, since the results obtained would have an important bearing on the theory of atmospheric electricity.

The same results may be shown in a simpler manner by the method invented by Saussure. This consists in attaching a leaden ball *f*, (Fig. 12,) to a long wire covered with silk or varnish, connected by means of a slight spring to the hook of an electroscope. When this bulb is thrown upward by means of a string and handle *p*, so as to rise to a considerable height in the air, the pith balls *g g*, of the electroscope diverge with positive electricity, and the wire is dis-connected from the instrument. That this effect is not due to the friction of the bulb and the air is shown by whirling it in a horizontal circle round the head; not the least sign of electricity in this case being exhibited: and that it is not charged by absorbing free electricity from the air, is proved by the fact that when the ball is thrown horizontally no excitement is manifest. The result is however just such as would be produced by the induction of the earth acting on the natural electricity of the wire and drawing it down to its lower extremity. A precisely similar effect would also be produced if the upper surface of the atmosphere were charged with this electricity. The intensity of the charge which the electroscope receives will depend upon the elevation to which the ball ascends, or in other words on the perpendicular component of the direction of the wire.

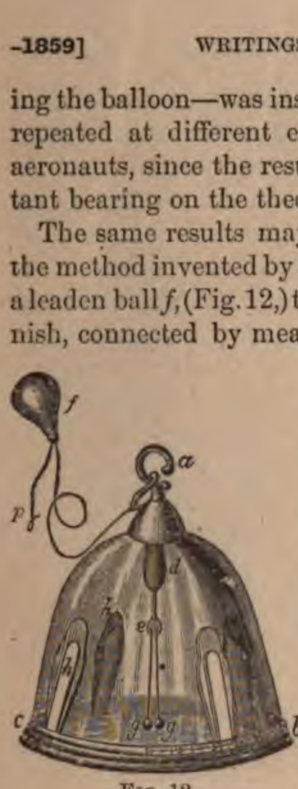

FIG. 12.

The method employed by Saussure in observing the variations of the electricity of the atmosphere illustrates the same principle. For this purpose he made use of one of his own electroscopes such as shown in Fig. 12. It consists of a bell-glass with a brass stem, *d e*, surrounded with sealing-wax, and two small pith balls, *g g*, suspended by very

fine wires: $c\ b$ is a metallic foot, and $h\ h$ slips of tin-foil pasted on the inside and outside of the glass to discharge the pith balls when the electricity is so strong as to cause them to strike the glass. To measure the electrical intensity with this instrument the hook a was removed, and its place supplied with a pointed brass rod. The electroscope was first brought in contact

FIG. 13.

FIG. 14.

with the ground as exhibited in Fig. 13; then held vertically as shown in Fig. 14, and gradually elevated until the leaves began to diverge. Saussure found that the height to which the instrument was required to be elevated before the leaves showed signs of electricity varied at different times, and he estimated the intensity of the electricity of the atmosphere by the inverse ratio of this height.

FIG. 15.

The explanation of this will be readily seen by a reference to Fig. 15, in which C, D, represents a portion of the surface of the earth negatively charged, and $a\ b\ c$, a perpendicular conductor terminated above and below by a bulb. In this

condition the un-saturated matter in *C*, *D* will act upon each atom of the fluid in the conductor, and tend to draw the whole down into the lower bulb; the atoms at *a* will not only be attracted downward by the action of the earth on itself, but also pressed downward by the attraction of the earth on all the atoms above it, and hence the intensity of the electricity of the lower part of the conductor will be increased by an increase in the perpendicular length of the rod. Now, if we connect the lower bulb of the rod with the earth by means of a good conductor, the redundant electricity of the lower end will be drawn off into the earth and will no longer re-act by its repulsion on the electricity of the rod to drive it back into the upper bulb, and hence this will become intensely negative, and in this condition it will be a salient point on the surface of the earth. If while the apparatus is in this condition we could touch the upper ball with an electroscope it would exhibit a negative charge.

If a conductor 20 feet in length were made to revolve on a horizontal axis, passing through the middle of its length so that it could be immediately changed from a horizontal to a vertical position, any change in the apparent condition of the atmosphere would be shown by the greater or less intensity of the balls, as in succession they passed the lower point of their circuit; and an apparatus in the form of radiating conductors like the spokes of a wheel, if made to revolve, would furnish a constant source of electricity. An apparatus of this kind was constructed by M. Palmieri, of Italy, and might be used perhaps with success in studying the condition of the atmosphere in ascensions.

The most convenient apparatus however for exhibiting electricity by the induction of the earth is that invented by M. Dellman, and shown in Fig. 16; which consists of a large brass ball *a* supported on a thick brass stem—held insulated inside of a glass tube by passing through corks of gum shellac. The apparatus is fastened to a pole which is temporarily elevated into the air by a windlass or the hand, on the top of a house. When it reaches the height intended, the wire *k*, connected with the earth below, is pulled, the end

FIG. 16.

of the bent metallic lever $g\,h$, is depressed, and the fork i brought into contact with the stem of the globe, and thus a perfect metallic connection is formed between the latter and the ground. The wire k is then released, the lever falls back, the ball is insulated from the earth, brought down, and applied to an electroscope, and in all cases, when the sky is clear, is found to be negatively electrified. If the wire k be insulated through its entire length, and terminated in a bulb at a little distance from the earth, and a pull be given to it by means of a rod of glass, at the instant of contact of the point i with the stem d, the lower bulb will exhibit a positive charge of electricity. The arrangement will, in fact, be precisely the same as that exhibited in the previous figure, (Fig. 15), namely, a vertical conductor, the upper end of which is rendered *minus* and the lower end *plus* by the induction of the earth. This effect is entirely due to induction, and is independent of any free electricity which may exist in the air. The results are exhibited with the greatest intensity during perfectly clear and dry weather; and are not observed when the conductor is placed horizontally, but the indications increase as its upper end is gradually brought nearer the perpendicular.

That these effects are not due to the free electricity of the atmosphere is satisfactorily shown by the original experiments of Peltier. For measuring the intensity of the inductive influence of the earth he made use of an electrometer represented in Fig. 17; in which $a\,b$, is a glass cylinder furnished with a wooden foot and a glass cover: through the centre of this is cemented a brass tube carrying a ball c at the top, and an arched straddling wire at the bottom. At the level of the foot of the arched wire is suspended a fine magnetized needle g, the height of which is adjusted by the screw h. The intensity of the electricity is measured by the divisions pointed out by the deflected needle on the slip

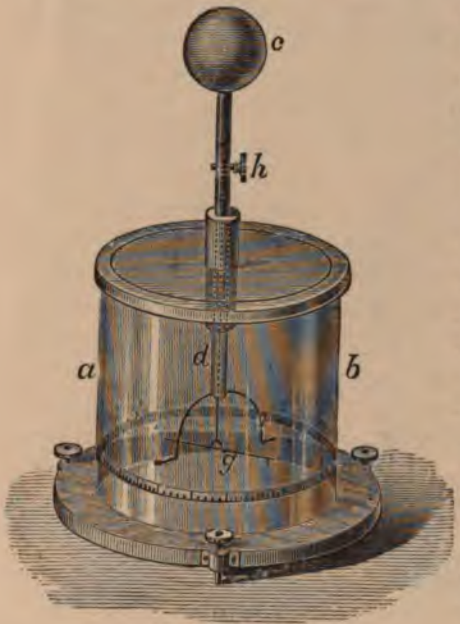

FIG. 17.

of paper surrounding the cylinder. This instrument, which is very sensitive, has been modified and improved by Dellman.

On the top of the flat roof of his house Peltier placed a flight of steps by which he could ascend holding in his hand an ordinary gold-leaf electroscope armed with a comparatively large sized polished ball. The ball of the electroscope was held at the height say of four feet above the roof of the house, and in this position it was touched by the end of a wire connected with the earth below. It thus formed the termination of a perpendicular conductor, and was of course negatively electrified—the bulb more intensely than the leaves below, but the stratum of air in which it was placed being in the same state it exhibited no signs of electricity. It was then elevated by ascending the steps to the height of six feet above, and held by the lower plate. The leaves in this case diverged with negative electricity, because the ball was still farther removed from the earth, and the attraction being lessened, the part of the electricity in the leaves was set free and ascended to the bulb by repulsion, leaving a deficiency in the leaves. When the electroscope was brought down to its first position the leaves again collapsed since there was again an equilibrium; and when the electroscope was depressed below its normal position the leaves became positively electrified by the increased attraction of the earth, and in this way the electroscope was

made to diverge, to converge, and diverge again, by simply changing its elevation.

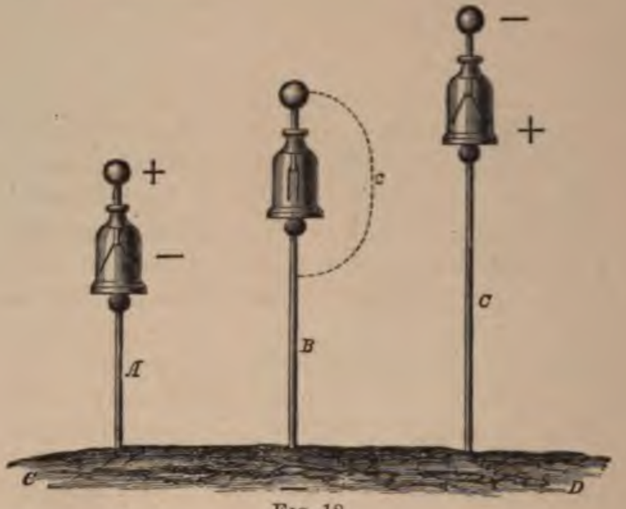

Fig. 18.

Fig 18 is intended to illustrate the condition of the electroscope in the three positions in which it is supposed to be supported on three metallic conductors of different heights. The electroscope brought into neutral condition by the ball is shown in the middle of the figure at *B*, in which the connection of the rod with the ball is indicated by the dotted line. When the electroscope is raised by the hand to a higher elevation its condition is exhibited by *C*, in which the greater height of the rod causes a greater amount of electricity to be drawn down, and the top of the rod and the bottom of the electroscope in connection with it to become more intensely negative, and hence to draw down into the leaves a portion of the natural electricity of the ball, and cause the former to diverge with positive excitement relative to the air around.

The condition of the electroscope when brought to a lower level is illustrated by *A*, in which the shortening of the conductor reduces the number of atoms on which the electricity of the earth acts, and hence those at the top are more pressed upward by their self-repulsion than in the former case, con-

sequently a portion of the natural electricity is driven into the upper ball and the leaves themselves diverge with a negative charge: the condition being opposite to that shown at *C*. The writer had the pleasure in 1837 of witnessing this interesting experiment as performed on a dry clear day by Peltier himself.

In order that the result may be shown with a slight change of elevation it is necessary that a large ball be employed, so that the effect may be multiplied by all the electricity of the greater surface. When the electroscope is terminated with the point of a fine needle, (though this is the best means of attracting electricity from the air at a distance,) no effect will be exhibited, provided the weather is dry and the sky cloudless.

From these experiments it appears evident that the positive electricity with which the air is apparently always charged in dry and clear weather, is not due to the free electricity of the atmosphere, but to the induction of the earth on the conducting materials of which the instruments are in whole or in part composed.

It is not difficult to deduce from the same general principles the apparent changes in the electrical state of the atmosphere at different times of the day and in different hygrometrical conditions of the air. Vapor of water mingled with the atmosphere renders the latter a positive conductor; and when the moisture of the air extends up as high as the upper part of the apparatus in Fig. 16, feeble negative electricity will by slow conduction be diffused through the adjacent strata, which acting upon the ball *a* will lessen the effect of the more intense action of the earth. While the latter tends to draw the natural electricity of the conductor down into its lower part and to render the upper end negative, the vapor around the ball will tend to draw it slightly upward and thus diminish the effect, and lead the casual observer to suppose that the air is less positively electrified. Peltier in this way has shown (as well as Quetelet and Dellman) that the variations of the electricity of the atmosphere observed from day to day, and at different times in the

twenty-four hours, correspond inversely with the variations in the amount of vapor.

The experiments we have thus far described are intended to establish the inductive character of the atmosphere in its condition of dryness and serenity, particularly during clear and cold weather.

We have employed movable conductors terminated by balls which have been of the most favorable form and relative dimensions to exhibit the effects of induction. The apparatus usually employed before the experiments of Peltier, were principally stationary insulated conductors terminated by points above, which as we have seen act powerfully in discharging electricity from a body, or in absorbing it from the surrounding medium.

If in the experiments with the apparatus, Fig. 16, the rod be terminated by a point instead of a ball, but feeble excitation will be observed during clear, cold weather, because the point exhibits so exceedingly small a surface that but very little electricity can be drawn down into the lower end before the intensity of attraction of un-saturated matter upwards comes into an equilibrium with the attraction of the earth downwards. With this instrument the observer would probably make a record to the effect that the electricity of the atmosphere was very feeble, whereas if the experiment were made with the apparatus previously described an opposite condition would be noted. But the result would be entirely different if the air were damp, and the insulated rod elevated to a considerable height: the negative intensity of the upper end would be sufficient to attract a portion of the natural electricity from the surrounding medium, even although this had become slightly negative by the previous induction of the earth. In this case the pointed conductor would indicate a large amount of electricity.

The intensity of the induction may even become so great as to absorb a portion of the natural electricity of the dry atmosphere as in the case of a very long wire, the upper end of which is furnished with a series of points, and raised to a great height by means of a kite. The points may attract

a portion of the natural electricity of the air, and thus produce at the lower end of the wire a series of sparks following each other, after the lapse of a certain time, at regular intervals.

From the foregoing it will be evident that in interpreting the indications of the two classes of instruments we have described, (which may be denominated those of induction and those of absorption,) we must keep constantly in view the principles that have been explained; and it is for want of a clear appreciation of these principles that so much complexity has been introduced in describing the otherwise comparatively simple effects of induction.

Electricity of the clouds.—The explanation of the thunder-storm and the tornado given by Peltier does not appear to us as satisfactory as could be desired. In common with most of the meteorologists of Europe, he fails to take into consideration the real character of the storm, which as we think has been fully established by theory and observation in this country, as consisting in the rushing up of the lighter air to restore the normal equilibrium of the atmosphere, disturbed or rendered unstable by the gradual introduction next to the ground of a stratum of warm and moist air. As an illustration of this disturbance, we may mention the fact pointed out to Arago, by Captain Hessard, as observed by him in the Alps, namely that during great heats there take place suddenly at the lowest stratum of clouds, upward rushings, extending vertically like rockets.

We shall endeavor to supply the deficiency we have mentioned in the exposition of Peltier, and to present on the principles of the induction of the earth in connection with the upward motion of the air, a logical explanation of the origin and continued supply of the great quantity of electricity developed in the meteors under consideration.

It follows from the principles of induction, that the upper end of all perpendicular insulated conductors must be electrified negatively, and the lower end positively, since the attraction of the un-saturated matter of the earth below will draw down the natural electricity of the conductor into its lower ex-

tremity, leaving a deficiency in the upper part. Now if we admit (agreeably to the theory of Mr. Espy,) that a cloud results from the upward motion of a mass of moist and heated air, the vapor of which is condensed as it ascends into the colder regions, thus forming a high perpendicular column of partially conducting material, it will be evident that by induction, the upper part of this cloud will become negatively electrified, and the lower part positively, as in the case of the conductor, Figure 15. The intensity of this excitement will depend upon the length of the vertical dimensions of the cloud, (which in many cases is exceedingly great,) and also upon the density, and consequently the conducting power of the vapor. The induction of the earth being very intense, a partial excitement of the atoms of vapor may take place even before the condensation of the whole mass has reached its maximum. If this be the case, a transparent mass of vapor, or that which is merely beginning to condense into cloud, will be electrified throughout its entire mass; and when the condensation of the vapor has gone so far as to render the interior a tolerably good conductor, the electricity of each atom will be repelled to the surface, as in the case of a globular conductor; the intensity will thus be highly increased, and while the rushing upward of moist air is going on, a series of discharges will take place between the upper and lower portions of the cloud.

FIG. 19.

It is asserted by Mr. Wise that the thunder-cloud, when viewed on one side from a sufficient elevation, presents the appearance of an hour-glass, the upper and the lower ends spreading out almost into two distinct clouds, as seen in Figure 19.

We find that the same form of the thunder cloud has been described by other aerial voyagers, also by Volta; and we are inclined to consider it the usual one presented by this meteor, since it is precisely that which would be produced by the self-repulsion of the upper and lower parts of the cloud, each charged as it is throughout its mass with the same kind of electricity. The middle of the perpendicular dimensions of the cloud as illustrated by the perpendicular conductor, Figure 15, will be neutral, and hence no tendency to bulge out at this point will exist. Mr. Wise also states that flashes of sheet lightning are constantly seen at *c*, in the middle space; and sometimes intense discharges from the upper to the lower part of the cloud;—appearances in exact conformity with the views here presented.

The immense number of discharges of lightning from a single thunder-cloud in its passage over the earth, through a distance in some cases of more than 500 miles, indicates a constant supply of electricity; and this is found in the continued rushing up of new portions of moist air, and in the successive renewals of the perpendicular column with fresh materials, the electrical equilibrium of which is disturbed by induction.

In the case of a tornado or water-spout, the ascending current of air is confined to a very slender column, in which the action is exceedingly intense; and since it is scarcely possible that the rushing in from all directions of the air below to supply the upward spout can be directed to precisely the same central point, a whirling motion must be produced. This will tend to limit the diameter of the spout, and to create a partial vacuum at the axis of the column, in which the moist air will have its vapor condensed by the cold of the sudden expansion, and a conductor will thus be formed extending from the cloud to the earth. Through

this conductor a constant convective discharge of electricity will take place, and all the phenomena described by Dr. Hare will be exhibited.

In this view of the nature of the tornado or water-spout, although we adopt with Franklin and Espy, as the characteristic of the commotion of the atmosphere, the rushing upward in the form of a column (on the principles of hydrostatics) of a stratum of heated and moist air which had accumulated at the surface of the ground, yet the phenomena are modified and increased in number by the great amount of electricity which must be evolved by the simple action of the continued elevation of new portions of a constant stream of moist air. Since the conductor in the case of the tornado or water-spout, extends downward near to the earth, and the discharge is continually taking place, the cloud which is spread out immediately above will be negatively electrified, and the upper portion of the cloud, as exhibited in Figure 19, will be wanting. The greater or less degree of conduction of the depending spout will vary the phenomena and give rise to the different appearances which have been seen at the surface of the water. When the conductor does not quite reach to the earth visible discharges of electricity will be exhibited, and the surface of water will be attracted upward. When the conducting material of the spout touches the surface of the water, the liquid will be depressed.

That the rushing up of the air with intense violence does take place in the column of a land or water-spout is abundantly proved by direct observation, and that electricity cannot be the cause of this action, but is itself an effect, is proved by the fact, that since the column of moist air extends to the earth, discharges of the fluid must be made through it which would soon exhaust the cloud, were it not constantly renewed. In some instances the meteor has been known to continue its destructive violence along a narrow line of more than two hundred miles in length. To merely refer this prolonged action to a whirling motion of the air, without attempting to explain on known principles of science, the renewed energy of the rotation, is to rest satisfied with a very partial anlysis of the phenomenon.

If by the action of an elevated horizontal current of air the upper part of a thunder-cloud be separated from the lower, we shall have a mass of vapor charged entirely with negative electricity, and from such a mass floating high in the atmosphere a new evaporation may take place by the heat absorbed directly from the sun. (Shown at *d*, Fig. 19.) The column of invisible vapor thus produced being a partial conductor elongated upward, the attraction of the earth will draw down a new portion of its natural electricity into the cloud from which the vapor was produced, and thus diminish its negative intensity. If now the upper end of this transparent column be condensed by the cold of the greater altitude into visible vapor, it will form a cloud of the second order of negative intensity. We shall thus have according to Peltier lower clouds intensely excited with positive electricity, clouds of medium elevation either neutral or slightly negative, and the highest cirrus clouds, which are formed by the secondary evaporation we have mentioned, strongly excited with negative electricity.

Since particles of ponderable matter similarly electrified repel each other, it is evident that the electrical state of the cloud must in some degree counteract the tendency to condensation which would result from the cold of the upper regions; and also the same action in the lower clouds will tend to prevent precipitation in the form of rain, even though the atoms of vapor are in a condition to coalesce into drops of water. It is evident also since the earth is negatively electrified, that the particles of vapor in the same state will be repelled farther from the surface, and those which are positively electrified will be drawn down. Hence, the negative clouds will tend to retain their elevated position, although they may be pressed downward by descending currents.

Negative clouds may also be formed near the surface of the earth by a detached portion of cloudy matter under a cloud more highly charged with positive electricity, which will cause the former by induction to discharge its positive electricity into the earth as well as a portion of its natural

electricity; and if the upper cloud be afterward driven away by the wind, the lower will be left highly negative.

Peltier states that he can determine from the appearance of a cloud whether it be positively or negatively charged. Clouds negatively electrified, (according to him,) are of a bluish gray color, while those which are positively charged are white and exhibit at the setting sun a red appearance.

From the foregoing considerations it must be evident that in addition to the disturbance which is produced in the atmosphere by the variations of heat and moisture we must take into account those that result from the changes in the electrical condition of the atoms of moisture. Though they may not be as important as the former, still they must modify the conditions of the general phenomena, and no theory of storms can be complete which does not include the effect of this agent.

On the principles we have developed, the discharges of lightning which are exhibited in volcanic eruptions are readily understood. The column of aqueous vapor, heated air, and other conducting materials, which sometimes rises to a great elevation from Vesuvius, must be subjected to the inductive action of the earth, and consequently the electricity of the upper end of the column, as soon as its elevation is sufficient to produce a condensation of the vapor, by the cold of the higher regions, must send down to the lower part of the column a large amount of electricity which when the length is great and the ascending stream rapid, will manifest itself in discharges of lightning.

In accordance with the same principles, thunder-storms have been artificially produced in a peculiar state of the atmosphere. About thirty years ago a farmer at Greenbush, near Albany, collected on a knoll in the middle of a field a large amount of brushwood, which was set on fire simultaneously at different points, and, burning, gave rise to an ascending column of heated air, extending to a great altitude. The air rushing in to supply the upward current assumed a rapid rotary motion, accompanied by a loud roaring and discharges of lightning of sufficient magnitude to

frighten the laborers from the field. The explanation in this case is too obvious to require a formal statement.

In the equatorial regions under a vertical sun masses of moist air are constantly rising during the daytime and producing electrical discharges to the earth. The vapor therefore which accompanies the reverse trade winds in the upper region must be negatively electrified, while the earth in the torrid zone must constantly be receiving electricity from the clouds. From this we may infer that there is a current of electricity through the earth, from the equator towards the poles and a neutralization by means of the air above, which may give rise to the aurora polaris.

Arago has described the different forms of lightning under three classes. The first class comprises the lightning which consists of a vivid luminous line or furrow, very narrow and sharply defined, the course of which is not a direct line, but is that denominated zig-zag. This peculiar form of lightning according to Moncel is referable to the effect of partial, interrupted conduction, and may be imitated by sprinkling iron filings on a plate of glass; the bifurcations of the discharge may also be referred to the same cause. The drops of rain distributed through the air perform the office of the particles of iron filings in the experiment, the repulsion of the electricity tending to separate it into different streams.

The next class consists of what is called "sheet lightning," which instead of being narrowed to bright sinuous lines, appears on the contrary to extend over immense surfaces. It not unfrequently has an intensely red tinge and sometimes a blue or violet color predominates. The color probably belongs to the flashes of lightning which take place at a great elevation, and seem to illuminate lower clouds, and thus to present the appearance of a broad flash.

We may also mention that flashes of lightning are sometimes observed in a summer evening without thunder, and known as "heat lightning." They are however merely the light from discharges of electricity from an ordinary thunder-cloud beneath the horizon of the observer, reflected from clouds, or perhaps from the air itself, as in the case of

twilight. Mr. Brooks, one of the directors of the telegraph line between Pittsburg and Philadelphia, informs us that on one occasion to satisfy himself on this point he asked for information from a distant operator during the appearance of flashes of this kind in the distant horizon, and learned that they proceeded from a thunder-storm then raging two hundred and fifty miles eastward of his place of observation.

The third class is called "globular lightning," which is remarkable (besides its peculiarity of form) for the slowness of its motion. The occurrence of this form of lightning is very rare, and were not the phenomenon well authenticated, we should be inclined to regard it as a delusion. But it does not comport with the cautious procedure of true science to deny the existence of all appearances which may not come within the prevision of what are considered as established principles. Although when facts of an extraordinary nature are related to us, they should not be received with that easy credence which might be due to less remarkable phenomena, yet after having fully satisfied ourselves of their reality, we must endeavor to collect all the facts connected with them, and to ascertain with accuracy the essential conditions on which they depend. Arago has given a number of instances of this remarkable form of the electrical discharge, the general appearance of which is that of a ball moving slowly through the air and sometimes when coming near a body, exploding with tremendous violence.

The only explanation which has been suggested for this remarkable meteor, and which at first sight appears to belong entirely to some other class of phenomena than those denominated electrical, is that which was in part suggested (I believe) by Sir W. Snow Harris. According to his hypothesis, the ball of light is the result of what is analogous to that which is known as a glow discharge, a phenomenon familiar to all who are in the habit of making electrical experiments. When a conductor connected with the earth is brought near a charged body, particularly when the air is damp, a partial silent discharge will take place, during which (although there may be no light perceptible in the space between the

two,) a glow of light will appear, attended with a hissing noise on the end of the conductor connected with the earth. Now, if we suppose that in the atmosphere between the cloud and the earth there exists a stratum or current of very dry air, while the remaining portions are in a very moist condition, and that the silent discharge from the cloud is taking place (for example) nearly perpendicularly to the earth, and passing through the dry stratum, then the partial interruption of conduction as the current of electricity passes through the dry stratum will give rise to the exhibition of light. Again if we suppose the cloud to be in motion, this appearance will travel with it, and the patch or glow of light will thus exhibit in mid-air a comparatively slow progressive motion, and disappear as if with an explosion, when a disruptive discharge takes place. This hypothesis can only be considered as an antecedent possibility, and is not presented as a full or satisfactory explanation; the phenomenon itself must be more frequently observed, and the associated condition of its appearance more minutely noted, before a definite hypothesis can be formed as to its cause.

Records of observations therefore with regard to this meteor are exceedingly desirable; they should however be made with scrupulous accuracy, and by persons accustomed to scientific investigations. We have found in examining testimony great difficulty in obtaining an accurate account of all the circumstances attending a peculiar occurrence of nature, from those who were present at the time and witnessed the phenomenon. It is astonishing how much the products of the imagination are mingled with the actual impressions made upon the senses, and how difficult it is to separate from the testimony of a witness what he actually saw and what he unconsciously infers from the previous crude conceptions of his mind, awakened at the instant by a powerful association of ideas. In the transit of the meteor which passed over a considerable portion of the United States, in November last, [1859,] a large number of persons declared that it fell in an adjoining field or in the water near by,

although it must have been at the time many miles in altitude above the surface of the earth.

Inductive action of the cloud.—A cloud formed as we have described must produce a great inductive effect on the earth beneath, and as it is borne along (from the west in this latitude) over the ground, the intensity of the electricity of the lower part must constantly vary, on account of the differing conductive capacity of the materials at or below the surface. For example, since water is a better conductor than dry earth, if the cloud is moving in a line that prolonged would cross a river, its course will frequently be changed, and in a similar way we can explain the fact that discharges of lightning more frequently fall on some places than others. Although the cloud may be impelled in the same direction by the wind, yet the attraction of the surface of the water (rendered more than naturally negative by induction,) will tend to draw it from its course. And since the induction acts at a distance through all substances, if a quantity of water or good conducting material exist below the surface of the earth, the cloud will be similarly affected. It frequently happens that when a heavy discharge of lightning passes near a house or descends along a rod, inductive effects are exhibited which are more startling than dangerous.

We have seen in the experiment described on page 693 (Fig. 9,) that an induced spark was exhibited at the edge of a large disc covered with tinfoil, in the lower story, by suddenly drawing the electricity from a similar disc in the upper part of a house. A precisely similar arrangement, but on a much more gigantic scale, is presented when a highly charged thunder-cloud is in the zenith of a building. Now if the intensity of this be suddenly diminished by a discharge to the earth, flashes of electricity and sparks from different objects within the house will be observed. The explanation of this is very easy. The free electricity of the cloud, which we may suppose to be positive, repels all the positive electricity of conductors and partial conductors into the ground, and renders them negative. They will be brought into this state very gradually however, either by the comparatively

slow approach of the cloud, or by its increase in intensity. The fluid therefore will escape into the ground without being perceptible in the form of sparks, but when the repulsion is suddenly relieved, at least in part, by a discharge of the cloud, the natural electricity rushes back and exhibits itself in flashes and sparks, and may even give shocks to persons in the vicinity. Although this sudden return of the electricity from the earth into which it has been driven, (in ordinary cases of conductors in a house supported by bad conducting materials,) is usually attended with but slight effects, yet it may under certain circumstances produce serious accidents, particularly when a person is in good conducting connection with the earth. A remarkable instance of this kind was described by Mr. Brydone, in a letter to the president of the Royal Society, in 1787.

Two laborers, each driving a cart loaded with coal, and sitting upon the front part, ascending a slight eminence, the one following the other at a distance of about twenty-four yards, as represented at *M* and *L*, Fig. 20, were conversing

FIG. 20.

about the thunder which was heard at a distance, when in an instant the man in the hinder cart was astounded by a

loud report, and saw his companion and the two horses which he was driving fall to the ground. He immediately ran to his assistance, but found him quite dead. The horses were also killed, and appeared to have died without a struggle. The hinder cartman had the horses and driver of the forward cart full in view when they fell to the ground, but he saw no flash or appearance of fire, and was sensible of no shock or uncommon sensation. Each wheel was marked with a bluish spot on the tire, as if the iron had been subjected at that place to an intense heat, and directly under these spots were two holes in the ground, from which the earth was removed as if by an upward explosion. Flashes of lightning had been seen and thunder heard by Mr. Brydone also, who was in the vicinity at the time, but these were at the distance of five or six miles, as shown by the time elapsed between seeing the flash and hearing the thunder. There were no marks however of the exit of the discharge upwards from the body of the man or of the horses, or any effect which could be attributed to a discharge immediately from the cloud. The accident was seen by another person, from a greater distance, who was also astounded by the loud report, saw the horses and man fall to the ground, and perceived the dust arise at the place, although he observed no lightning or fire at the time. A shepherd in a neighboring field, during the same storm, observed a lamb drop down dead, and felt at the same time as if fire had passed over his face, although the lightning and clap of thunder were at a great distance from him. This happened a quarter of an hour before the accident to the cartman, and not over three hundred yards from the same spot. A woman making hay near the bank of the river close by, fell suddenly to the ground, and exclaimed to her companions that she had received a violent blow on her foot, and could not imagine whence it came.

A scientific analysis of these phenomena is given by Earl Stanhope, on principles similar to those of induction, which we shall translate into the precise language of that theory. Let us suppose a cloud eight or ten miles in length to be extended over the earth in the situation repre-

sented by A B C in Fig. 20, and let another cloud D E F be situated between the above-mentioned cloud and the earth. Let the two clouds be supposed to be charged with the same kind of electricity, and both positive. Let us further suppose that the lower cloud D E F be only so far from the earth as to be just beyond the striking distance, and the man, cart, and horses to be at L, under the part E of the cloud which is nearest the earth. Now let the remote end C of the upper cloud approach the earth within striking distance, and suddenly discharge itself at G. The effect which would be produced by this arrangement, at the moment of the discharge Cc G, will be understood by considering the condition of the electricity in the two clouds, and in the earth a moment previous to the discharge. Both clouds being positive, the two will act upon each other by repulsion, the free electricity of the lower cloud will be driven down into its lower surface, and will be accumulated particularly in the point E nearest to the earth. The ground underneath the lower cloud, and more especially at L, where the distance is least, will become highly negative. The natural electricity will be driven down into the ground by repulsion, and will be retained there as long as this condition remains, but when a discharge takes place at the point C G, if the cloud B be a good conductor, the repulsion at A and D will be suddenly removed, and the natural electricity of the earth will return with a rush to the surface and pass beyond its point of natural equilibrium, as in this case into the man and horses. The loud report was caused by the discharge from D to A, which was invisible to the eye of the spectators on account of the density of the lower cloud.

An experimental illustration of the effects produced in this case may be readily furnished by charging two conductors, arranged in the relative position of the two clouds. At the moment a spark is drawn from the end C a discharge is observed at D A. The death of the lamb and the shock felt in the foot of the woman were both produced according to this view by the sudden rushing up of the natural electricity of the ground, when the repulsion in the upper cloud was in part diminished by the distant discharge.

The inductive action at a distance which we have described affords a rational exposition of the effects which are perceived by persons of nervous sensibility on the approach of a thunder-storm, and may also be connected with the change which is said to take place suddenly in liquids in an unstable condition, such as the souring of milk and other substances near the point of fermentation. But whether the latter effects are due to the inductive action of the electricity or the tremor produced by the thunder, has not to our knowledge been definitely settled. If the effects are due to induction, it is probable that they would be greater in the case of milk in a metallic pan resting on the earth, than in one of glass, supported on glass legs or on a thick cake of bees-wax.

Precautions with regard to lightning.—Men have often been struck by lightning in open plains, and since the human body is a good conductor of electricity, from the principles above stated it must be evident that when standing it would be more likely to be struck than any point on the earth in the vicinity. There is less danger in a horizontal position, particularly if the person be resting on some non-conducting substance which would prevent the natural electricity from descending into the earth. Near the foot of a tall isolated tree is always considered a dangerous position, and this is in accordance not only with facts but well-established principles. The upper part of the tree being a partial conductor, particularly if covered with foliage, will become electrified by induction, will attract the discharge to itself, and in the passage of the lightning toward the earth it will act with energetic induction on all surrounding objects, and since the body of the man is a better conductor than the wood, the instantaneous inductive effect of the descending bolt will be greater on the head of a man than on the remaining part of the tree, and hence it will diverge from the line it was pursuing, break through the air, and pass through the body of the man. To attempt to explain this phenomenon by merely saying that the electricity leaves the tree because the human body is a better

conductor than the wood is to attribute to this agent prescience and forethought, but by an application of the principles of induction, the whole is referred to the simple action of attraction and repulsion. In the interior of a house the safest position we can well imagine is that of being horizontally suspended in a hammock by silk cords in the middle of a room, and perhaps the next, that of lying on a mattress or feather bed on a wooden bedstead the materials of which are very imperfect conductors. It is scarcely necessary to say that if the bedstead be in the middle of the room, at a distance from the wall, the danger will be still less.

It may perhaps be well to dwell for a moment on the explanation of the foregoing statement. Let us suppose a man to be standing on a large piece of bees-wax, which is almost a perfect non-conductor, and exposed to a cloud highly charged with positive electricity. A portion of the natural electricity of his head would be drawn down into his feet; the former would become negatively electrified and attract the lightning of the cloud, while the latter would repel it; the tendency to be struck would be on account of the difference of these two actions. If the man stepped off the non-conducting wax on to the earth the redundant electricity which had collected in his feet would be discharged, his head would become still more negatively electrified, the repulsion which existed in the other case would disappear, while the attraction would be increased, and hence the tendency to be struck would be much greater.

Let us next consider what would take place if a man should be extended horizontally on a large disc of beeswax. In this case the upper part of the body, or that toward the sky, would become negative, and the lower part, or that in contact with the beeswax, would become positive, and the attractions and repulsions would be exhibited as in the first instance, but with less energy, because their foci would be much nearer each other, and consequently they would act with almost equal effect; while the repelled electricity not having space into which to descend, a less quantity of it would be repelled from each point of the upper surface. If

the disc of wax were placed above the man's head while in the standing position it would not screen the repulsive energy in the cloud, which like gravitation acts through all bodies; the induction would take place as before, the head would become highly negative, while the natural electricity which had been driven down would escape into the earth. The effect would therefore be the same as if the individual were standing on the earth without the intervention of the non-conducting material. A descending bolt would be attracted towards the head, and if the tenacity of the bees-wax were not sufficient to withstand a disruptive discharge, the body would be injured. From a mis-apprehension of these principles it has been supposed that the protection is increased by a slight covering over the body of silk or feathers, or by interposing a plate of glass between the sky and body; but it is well known that fowls and other large birds are struck, the slight covering of feathers affording no protection while the feet are in connection with the earth.

From the conducting capacity of the soot usually lining a chimney, and of the smoke and heated air which ascend from the flue, it will be clear that the vicinity of the fire-place during a thunder-storm is not the safest position that may be chosen in a house. A person leaning out of an open window may also not be in a very safe position, because the outside of the house, wetted with rain, will be rendered a partial conductor, and a descending charge along the wall may reach the body projecting beyond the surface. The induction is always greater where there is a large amount of conducting material, hence barns filled with damp hay will be more liable to be struck than when empty. Besides the action of induction in this case, it is generally supposed that the danger is increased by the ascent of vapor from the barn at the season mentioned; and this supposition, which is in accordance with scientific principles, is apparently borne out by observation.

On the principle of the increase of induction in the collection of a large number of conducting bodies in a given space, the assemblage of persons in churches, or other places

of public meetings, increases the tendency of lightning to fall on the edifice. The inductive action will be slightly increased when the audience assumes a standing position. For a similar reason sheep which are crowded together during a storm are frequently killed by lightning. The fact has several times been noticed that when a discharge passes through a number of animals arranged in a straight line, those which are at the extremities of the row suffer most; and this has been observed even when the animals were not in immediate contact with each other, as for example a number of horses in a series of stalls. It is probable that the heated air between the horses may have served as a conducting medium, and that the effect can be referred to the increase of intensity which always takes place in the electrical discharge at the points where the air is ruptured, or where the electricity enters and passes out.

The probability of injury from lightning is slight, even in this country where thunder-storms are comparatively frequent in the summer; and though it may be well to observe proper precautions, yet on account of the small risk to which we are subjected we should not deprive ourselves of the gratification of observing and studying one of the most sublime spectacles of nature; and indeed we know of no better way of overcoming the natural dread which many persons have of this meteorological phenomenon than by becoming interested in its scientific principles, and in studying, in connection with these, its appearance and effects.

Effects of the introduction of gas and water pipes.—Since the use of gas has become so general in our cities as to be considered almost one of the essentials of civilized life, a new source of danger has been introduced. Persons who repudiate the use of lightning-rods because they attract the electricity from the clouds should reject the introduction of gas—particularly in the upper stories of their dwellings, since the perpendicular pipes must act as the most efficient conductors between the cloud and the earth. We say the most efficient because they are connected below the ground with a plexus of pipes, in many cases of miles in extent, the whole of which

is rendered highly negative by the induction of a large cloud; and since this action takes place with as much efficiency through the roof of a house and the chamber floors as it does through the open air, a gas-pipe within a house, (in proportion to its height) would powerfully attract any discharge from a cloud in its vicinity.

To obviate the danger from this source, the lightning-rod which rises above the top of the building should be placed in immediate metallic contact with the plexus of gas-pipes outside the house. If as is very frequently the case, the rod is made to terminate by simple insertion of a few feet in the dry earth, while the gas-pipe is connected with miles of metallic masses, rendered highly negative by induction, the path of least resistance, or of most intense induction from the cloud to the earth, will be down the rod to some point opposite the gas-pipe, then through the house and down the pipe into the great receiver below. This conclusion, from the theory, is fully borne out by observation. On Friday evening, May 14, 1858, a house in Georgetown, D. C., was struck by lightning, and on Saturday, the next evening, another house was struck in Washington, on Seventeenth street, north of Pennsylvania avenue. The writer carefully examined the conditions and effects in both cases, and found them almost identically the same. The houses were similarly situated, with gable ends north and south, and attached to the west side of each was a smaller back building. The lightning-rod of the house at Georgetown was placed on the southern gable. It terminated above in a single point, and its lower part was inserted into hard ground, through a brick pavement, to the depth of about five feet. The lightning fell upon the point, (which it melted,) passed down the rod until it came to the level of the eaves, thence leaving the conductor, it passed horizontally along the wet clapboards to the southwest eave or corner of the house, thence down a tinned iron spout to the tin gutter under the roof of the back building, and thence it pierced the wall of the house opposite the point on the outside of the back building corresponding to the position of a gas-pipe in the interior, after which no further effects of it could be

observed. A small portion of the charge however diverged to a second gas-pipe in an adjoining room. The back building was of wood, and the passage of the charge appeared to be facilitated by a large nail. The discharge was marked throughout its course by the effects it produced: 1st, the point of the rod was melted; 2d, a glass insulating cylinder through which the upper part of the rod passed was broken in pieces; 3d, the horizontal clapboard extending from the rod to the eave was splintered; 4th, the tin of the gutters and spout exhibited signs of fusion; 5th, the plaster was broken around the hole through which the charge entered the house.

The lightning-rod of the house which was struck in Washington was placed on the north gable; the electricity left the conductor at the apex of the roof, descended along the angle of the coping and the roof, which was lined with tin, to the northwest eave of the main building, thence southward along a tin gutter until it met a perpendicular tin spout, which conducted it to a point on the outside of the back building corresponding to a gas-pipe within; it then pierced a nine-inch brick wall and struck the gas-pipe, that which was embedded in the wall of the main building, at the distance of 15 inches horizontally north of the hole which it pierced in entering the interior. A lady was sitting with her back toward the point where the discharge entered the gas-pipe, at the distance of 18 inches, and though she was somewhat stunned at the time, and perceived a ringing sensation in her ears for some time after, she received no permanent injury.

At the last meeting of the American Association, Professor Benjamin Silliman, Jr., described two instances of a similar character, in which the discharge from the cloud struck twice, in different years, the lightning-rod of the steeple of a church in New Haven, left the conductor and entered the building, to precipitate itself on the gas-pipes of the interior. The remarkable fact was stated in connection with this occurrence, that the joinings of the gas-mains under the street on the outside of the building were loosened, apparently by the mechanical effect of the discharge, and

the company was obliged to take them up and repair the damage to prevent the loss of gas. An occurrence of this kind might perhaps lead the proprietors of gas-works to object to the proposition of connecting the end of the rod with their mains; but they should recollect that if means be not furnished to prevent the danger consequent upon the use of gas, a less amount of the article will be consumed; and furthermore that giving more efficiency to the inductive action of the rod on the cloud by the connection we have proposed, the tendency to a discharge will be lessened; and finally, that if the connection be not formed, the discharge from the cloud will itself find the main through the gas-pipes within the house.

There is another source of danger of a similar character in cities supplied with water from an aqueduct; the pipes in different stories of the buildings, connected with the water mains which under-lie the city, in most intimate connection with the earth, are subject to a powerful induction from the cloud above, and therefore will attract any discharge which may be passing in their vicinity, or even determine the point at which the rupture of the stratum of air between the cloud and the house shall take place. In this case the lightning-rod should also be connected with the pipes under ground, in order that the induction through the rod should be as perfect as possible, and that the consequent attraction may confine the charge and transmit it entirely to the large mains, and from them to the earth. Houses are sometimes supplied with water from the roof, collected in tanks in the loft, whence it is distributed by pipes to different parts of the building. This arrangement also tends to invite the lightning in proportion to the perpendicular elevation of this system of conductors. The lower ends of these are not usually in very intimate connection with the earth, and therefore a less powerful induction takes place than in the other instances we have mentioned. They should however be placed as in the preceding case in good metallic connection with the lightning-rod on the outside of the house. The same remark applies to steam and hot-water pipes used for heating large buildings.

The different sides of a building are not all equally exposed to accident from lightning. Thunder-clouds in this latitude approach us from the southwest, and hence the part of the house which faces this direction is not only more exposed to the fury of the storm, but also to the effects of the electrical discharge. The position then of the lightning-rod on this account is not to be neglected. The soot which lines a chimney is a good conductor, and hence the discharge not unfrequently passes into the house along the interior surface of this opening. But there is another circumstance which renders the chimney still more liable to be struck, namely, the column of heated air and smoke which ascends from it into the atmosphere when there is a fire burning below. These are tolerably good conductors of electricity, and as the latter may under some conditions extend to a considerable height in the atmosphere, they are sufficient to attract the descending discharge and determine its course to the chimney. A rod should therefore be placed on every chimney through which a column of heated air ascends during the season of the occurrence of thunder-storms.

Among the many novel propositions urged upon the attention of Congress there was one a few years ago with results having a bearing on this subject. For the purpose of lighting the public grounds an appropriation was made to erect a mast eighty feet in length on the top of the dome of the Capitol. This mast was surmounted by a lantern of about six feet in height and of corresponding diameter, containing a large number of gas-burners, and terminated above by a gilded copper ball of about a foot in diameter. After this gigantic apparatus had been erected in defiance of all the principles of architecture and illumination, the author of this report was called upon for his opinion as to the effect of lightning upon it. The answer given was that since the simplest method of obtaining electricity from the atmosphere is to elevate a piece of burning tinder on the end of a fishing-rod, the apparatus placed on the dome of the Capitol would be a collector of electricity on an immense scale, and therefore would probably be struck by lightning. As if to verify

this prediction, on the occurrence of the first thunder-storm the apparatus received a discharge from the cloud, which fused several holes in the upper part of the ball and indented the surface, but fortunately did no damage to the building. The apparatus was then removed, and the ball deposited in the museum of the Smithsonian Institution as an interesting illustration of the chemical and mechanical effects of a discharge of lightning.

Effects of telegraph wires.—In 1846, the Hon. S. D. Ingham, of Pennsylvania, requested the opinion of the American Philosophical Society as to whether security in regard to accidents from lightning is increased or lessened by the erection of telegraph wires, the poles of which are placed by the side of the roads along which persons with horses and carriages are constantly passing. The subject was referred to the writer, from whose report in regard to it the following facts and deductions are given.* The wires of a telegraph are liable to be struck by a direct charge from the clouds, and several instances of this kind have been observed. About the 20th of May, 1846, the lightning struck the elevated part of the wire which is supported on a high mast where the wire crosses the Hackensack river. The fluid passed along the wire each way from the point which received the discharge for several miles, striking off at regular intervals down the supporting poles. At each point where the discharge took place along a pole a number of sharp explosions were heard in succession, resembling the rapid reports of several rifles. During another storm the wire was struck in two places on the route between New York and Philadelphia. At one of these places twelve poles were struck and at the other eight. In some instances the lightning has been seen coursing along the wire like a stream of light, and in one case it is described as exploding from the wire in several places, though there were no bodies in the vicinity to attract it from the conductor.

That the wires of the telegraph should be frequently struck

*[Proceedings Am. Phil. Society, June 19, 1846, see *ante*, vol. I, p. 244.]

is not surprising when we consider the great length of the conductor, and consequently the many points through which it must pass along the surface of the earth peculiarly liable to receive the discharge from the heavens. Besides this, from the great length of the conductor, its natural electricity, driven to the farther end or ends of the wire, will be removed to a great distance from the point immediately under the cloud, and hence this will be rendered more intensely negative and its attractive power thereby highly increased. It is not probable however that the attraction, whatever may be its intensity, of so small a wire as that of the telegraph can of itself produce an electrical discharge from the heavens, although if the discharge were started from some other cause, (such as the attraction of a large mass of conducting matter in the vicinity,) the attraction of the wire might be sufficient to change the direction of the descending bolt and draw it, in whole or in part, to itself. It should be recollected also that on account of the perfect conductivity of the wire, a discharge on any one point of it must affect every other part of the connected line although the whole may be several hundred miles in length.

That the wire should give off a discharge to a number of poles in succession is a fact that might have been anticipated, since the electricity would by its self-repulsion tend to send a portion of itself down the partial conducting pole, while the remaining part, attracted by the wire in advance of itself, rendered negative by induction, would continue its passage along the metal until it met another pole, when a new division of the charge would take place, and so on. The several explosions in succession, heard at the same pole, are explained by the fact that the discharge from the cloud does not generally consist of a single wave of electricity, but of a number of discharges in the same path in rapid succession, so as in some cases to present the appearance of a continuous discharge of a very appreciable duration; and hence the wire of a telegraph is capable of transmitting an immense quantity of the fluid thus distributed in time, over a great length of the conductor.

From the foregoing in regard to the direct discharge, we think the danger to be apprehended from the electricity leaving the wire and striking a person on the road is small. Electricity of sufficient intensity to strike a person at the distance of twenty feet from a perfectly insulated wire would in preference be conducted down the nearest pole. It will however in all cases be most prudent to keep at a proper distance from the wire during the existence of a thunder storm, or even at any time when the sound of thunder is heard in the distance.

In case of wires passing through cities and attached to houses they should be provided at numerous points with electrical conductors to carry off the discharge to the earth. These consist of copper wires intimately connected with the earth by means of a plate of metal at the lower end, extending up the pole or side of the house, and terminating in a flat plate above, parallel to another plate of metal depending from the wire of the telegraph. The two plates are separated by a thin stratum of air, or some other non-conducting material, through which the intense discharge from the clouds will readily pass and be conducted to the earth, while the insulation of the wire for the purposes of the telegraph is un-impaired.

There are other electrical phenomena connected with the telegraph which, though frequently annoying to the operator, are not attended with the same degree of danger to his person. These are immediately referable to induction at a distance, and consist entirely in the disturbance of the natural electricity of the wire. Suppose a thunder cloud to be driven by the wind in such a direction as to cross at right angles, for example, the middle of a long line of telegraph wire. During the whole time the cloud is approaching the point of its path directly above the wire, the repulsion of the redundant electricity of the former will constantly drive the natural electricity of the latter farther and farther along the line, so that during the approach of the cloud a continuous current will exist in each half of the line. When the centre of action of the cloud arrives at the nearest point of the wire

the current will cease for a moment, and as the repulsion gradually diminishes by the receding of the cloud the natural electricity of the wire will return to its normal condition by a current opposite to that which was first manifested. Since the thunder clouds over the greater portion of the United States move from west to east, lines in a north and south direction are more liable to currents of this class, which may be denominated those of statical induction.

There is another class of currents which although they continue but for an instant are more intense than the preceding, giving rise to vivid sparks, and are due to the dynamic induction at a distance of a discharge from a cloud to a cloud, or from a cloud obliquely to the earth.

The greatest intensity is produced when the path of the lightning is parallel to the line of the telegraph, and in this case, under favorable circumstances, sparks and shocks may result from a discharge between two clouds at the distance of several miles. In these inductive actions there is no transfer of the electricity from the cloud to the wire, but simply the disturbance of the natural electricity of the conductor by the repulsive energy exerted at a distance. As already stated, nothing screens this induction; for like magnetism and gravitation, it acts as freely through the roof of a house, the air, and all other non-conducting materials as it probably would do through void space. A similar result is produced on long lines of railway, and sparks have been observed at the joining of the rails not in perfect metallic connection, particularly at the turn-tables.

The electrical telegraph is sometimes disturbed by other influences. It is evident from what we have said in reference to elevated bodies, that if a line of wire extends over a high hill the intensity of electricity will be greater at the high points than below, particularly during the occurrence of fogs; the wire will tend to absorb the electricity of the air, and transmit it from the higher to the lower portions; also during the fall of rain and snow on one portion of a long wire while clear weather exists at another, there would be a current of electricity observed in the intermediate portion.

During very warm weather a feeble current is observed at different periods of the day, which may be referred to thermo-electricity. It is well known that when one end of a long conductor is heated and the other cooled, a current of electricity will pass from the hotter to the colder extremity, and this will be continued as long as the difference of temperature exists. Extended lines in a north and south direction are most favorably situated for observing a current of this class. Currents of electricity of sufficient intensity to set fire to pieces of paper, have also been observed in connection with the appearance of the aurora borealis

Means of Protecting Buildings.

Although much has been written and said in disparagement of the admirable invention of our illustrious countryman, Franklin, yet an attentive consideration of all the facts, even independent of theory, fully establishes its great importance.

1st. It is well known, from general experience, that lightning directs itself to the most elevated portions of edifices. Cotton Mather declares that lightning is under the immediate direction of the "Prince of the powers of the air," because church steeples are more frequently struck than any other objects. It is therefore evident that the preservative means, whatever they may be, should be applied to the upper portions of a building.

2d. If other conditions be the same, lightning directs itself in preference—to metals. When therefore a mass of metal occupies the more elevated portion of a house we may be nearly certain that lightning, if it falls upon the building, will strike that point.

3d. Lightning when it enters a metallic mass does mischief only where it quits the metal, and in the vicinity of the point at which it issues. A house therefore entirely covered with metal would be safe, provided this covering were intimately connected with the ground by metallic conductors of sufficient size. When there are upon the roof or in any of the upper stories of an edifice several dis-

tinct metallic masses completely separated from each other, it will be difficult to tell which of them will be struck in preference. The safest practice is to unite all these masses by rods or bands of iron, copper, or other metal, so that each of them may be in metallic communication with a rod which may transmit the lightning to the damp earth.

"We thus deduce from facts established by observation alone without borrowing anything from theory," says Arago, "a simple, uniform, and rational means of protecting buildings from the effects of lightning. But when we refer, in addition to these facts, to the precise principles or laws of electrical action, as deduced from cautious and refined experiments in the laboratory, we are enabled to give rules for the protection of buildings which, when properly observed, reduce almost to insignificance the danger to be apprehended from the ordinary occurrences connected with the terrific exhibitions of thunder-storms."

From what has been said on the principles of induction, and also on the fact of the negative condition of the earth, it will be readily perceived that the upper end of an elevated conductor must become highly negative under the repulsive energy of a positive cloud, and though it may not be sufficient in itself to cause a rupture of the thick stratum of air intervening between the cloud and the earth, yet if a discharge does take place in the vicinity of this body, it will be drawn toward it, and if the conductor extends to the earth, and is in intimate connection with the damp ground, the discharge will pass innoxiously into this great reservoir. We further know from theory as well as experiment and observation, that the intensity of attraction is increased when the conductor is terminated above in a single sharp point. Although the attraction at a distance may be greater on a metallic globe of a few feet in diameter than on a metallic point, (since the former is able to receive a greater induced charge, which by the well-known law of attraction will act as if the whole were concentrated at the centre of the sphere,) yet the intensity of action of the point and its tendency to open a passage through the air is so great that it is preferred in protecting a given circumscribed space from lightning.

The question has been agitated whether one point or a number on the same stem is to be preferred? But this question may be readily settled, provided the reason for preferring a point to a ball or a globe is legitimate, since the surface of a ball itself may be considered as made up of an infinite number of points, and therefore a number of points close together must re-act upon each other, and thus approximate in result the effect of a continuous spherical surface. In the case of three points on the same stem, the whole amount of inductive effect produced in the rod is practically divided into three parts, and is therefore less concentrated than in the case of one point; and although at a distance the effect of the three may be equally energetic, yet the one point tends more effectually to rupture the air, and open (so to speak) a passage for the discharge from the cloud.

In reference to the subject of the termination of rods by balls or points, much discussion took place on the early introduction of the invention of Franklin, and the subject was elucidated by a very ingenious experiment made by Beccaria, in 1763, which is quoted by Arago. On the roof of a church at Turin this eminent electrician erected a rod of iron insulated on one of the flying buttresses. The upper part of this rod, which was terminated by a single metallic point, was hinged a few inches below the top, so that by merely pulling a string the point could be directed horizontally, upward, or downward. When the point was pulled downward during the presence of a thunder-cloud in the zenith, the lower end of the rod gave no sparks; but when the point was suddenly directed upward, in a few moments sparks appeared. When the point was downward, the rod presented a blunt termination toward the sky; when upward a sharp point. It might be well to repeat this experiment with some slight variation in the apparatus, in order to establish or dis-prove, by direct observation, the inference from theory that a single point acts more energetically than three or four points, terminating the same rod. The substance which terminates the conductor should be such as to preserve its form when subjected to the action of the weather, and be infusible by a stroke of lightning.

The first requisite is found in the tip of an iron rod gilded, to prevent its becoming blunted by rust; but a point of this kind, though it may protect a building from the first discharge which strikes it, will be melted, and the intensity of its action thereby diminished in the case of a subsequent explosion. At the upper termination of the lightning-rod, a small cone of platinum attached to a copper socket which fits on the top of the rod, made conical for that purpose, is now usually employed. Tips of this kind are now generally offered for sale in the large cities. The quantity of platinum on them however is generally too small, since we have known them in several instances to be fused by a discharge of lightning. The point itself should be the apex of a solid cone of platinum or of a thick plate of that metal, fastened by screwing or soldering to the copper socket.

We frequently see announcements in the papers of great improvements in lightning-rods, for which patents have been obtained, and among these boasted improvements have been the application of magnetized steel points to receive the lightning; but this invention, like most of the others which have been given to the public for the same purpose, is the result of some imaginary analogy, or of sheer charlatanism. It rests upon no foundation of observation, experiment, or theory. The magnetization of a bar, so far as it has any effect, tends to cause the electrical discharge to revolve around it, and to render the iron very slightly, if anything, a less perfect conductor.

The horizontal distance from a rod to which the protecting influence extends, is a question of considerable importance. It has generally been admitted that the point of a lightning conductor protects a horizontal circular space with a radius equal to twice its own height; that is, if the elevation of a rod above a flat roof be ten feet, it will protect a circular space of twenty feet radius, or forty feet diameter. But this rule cannot always be depended upon; for although it may be true in regard to buildings of stone or brick, with an ordinary sloping roof covered with tiles or slate, it would scarcely hold good if considerable masses of

metal formed part of the building or the roof. Observations have been recorded of parts of houses being struck within the limit just mentioned as that of protection; but scarcely any of them are satisfactory in determining the point, since it appears from the evidence that in several cases there were separate masses of metal which formed independent conductors, and in the other cases there was no evidence that the rod was in proper connection with the earth. In order to protect an extensive building, it will evidently be necessary to arm it with several lightning-conductors, and the less their height, the greater must be their number.

In the case of a tall steeple, it may be well to establish points at different elevations, by branches from the main rod; for if it be true that the rod merely attracts the lightning which has been determined by the earth itself, or some material under the ground, the discharge in its passage along the line of least resistance to the point at which it was aimed, may not be made to deviate from its direct course by the attraction of the distant elevated point, and may strike a lower portion of the building. Suppose for example a thunder-cloud is on the west side of a high steeple, and the point of attraction, which may be damp earth, a pool of water, or other conducting material on the surface or under the ground at the east end of the church: the discharge from the cloud, in its passage to the point of attraction, may strike a lower portion of the building, the action of the elevated point not being sufficient to deflect it from its course. This inference is in accordance with actual observation. Mr. Alexander Small wrote to Franklin, from London, in 1764, that he had seen in front of his window a very vivid and slender lightning discharge pass low down, without a zig-zag appearance, and strike a steeple below its summit.

It becomes a matter of interest to ascertain whether the action of an assemblage of conductors, such as is usually found in cities, produces any sensible effect in diminishing the electrical intensity of the cloud, or in other words whether their united influence produces any sensible diminution of the destructive effects of thunder-storms. Late researches

have shown that but a comparatively small amount of development of electricity is sufficient to produce great mechanical effects. Faraday has even asserted that the quantity of electricity necessary to de-compose a single grain of water, (and consequently the electricity which would be evolved by the re-composition of the same elements) would be sufficient to charge a thunder cloud, provided the fluid existed in the free state in which it is found at the surface of charged conductors. A similar inference may be drawn from the great amount of electricity developed by the friction of the small quantity of water existing in steam, as the latter issues through an orifice connected with the side of the boiler. We also find that an iron rod of three-fourths of an inch in diameter, is of sufficient size to transmit to the earth without any danger to surrounding objects a discharge from the clouds, which may be attended with a deafening explosion and with a jar of thunder powerful enough to shake the building to its foundation.

The intrepid physicist, De Raumer, sent a kite up into the air to the height of 400 or 500 feet, in the cord of which was inserted a fine wire of metal. During a thunder-storm he drew from the lower extremity of the cord not mere sparks but discharges nine or ten feet long and an inch broad.

Beccaria erected a lightning-rod which was separated in the middle by an opening, the upper part being entirely insulated. During thunder-storms intense discharges darted incessantly through the opening. So constant were these that neither the eye nor the ear could readily perceive the intermission.

"No physicist," says Arago, "will contradict me when I say that each spark taken singly would have given a shock attended with pain, that ten sparks would have numbed a man's arm, and a hundred would have proved fatal. Now a hundred sparks passed in less than ten seconds, and hence in every ten seconds there was drawn from the cloud a quantity of electrical energy sufficient to kill a man, and six times as much in every minute." Arago calculates in this way that all the lightning conductors of the building in

which the experiment was tried took from the clouds as much lightning as would have been sufficient in the short space of an hour to kill upwards of three thousand men. From the foregoing facts and conclusions we may infer that the lightning-rods of a city have considerable effect in silently discharging the clouds, and in preventing explosions which would otherwise take place; but we must recollect that on account of the upward rushing of the moist air, the electricity of the cloud is constantly renewed.

We cannot suppose that the sparks observed by Beccaria in his experiment, and the ringing of bells by Franklin, were due entirely to the electricity immediately received from the cloud. By the powerful induction of the redundant electricity of the latter, and the negative action of the earth beneath, the natural electricity of the top of the rod would be forced down into the earth, the point would become intensely negative, and in this condition would draw from the air around streams of electricity, and in this way a large volume of air around the top of the rod would become negatively electrified; and in case a discharge of lightning took place its first effect would be to neutralize or fill up, as it were, this void of electricity in the large mass of air surrounding and above the top of the rod, before the remainder of the discharge could pass to the earth. The peculiar sound which is heard when a discharge from a thunder-cloud is transmitted through a lightning-rod may possibly be attributed to this cause.

The Smithsonian building, with its high towers, situated in the middle of a plain, at a distance from all other edifices, is particularly exposed to discharges of lightning, and we have reason to believe that in as many as four instances within the last ten years the lightning has fallen upon the rods and been transmitted innoxiously to the ground.

In two of the instances the lightning was seen to strike the rod on one of the towers; in a third, a bright spark due to induction and attended with an explosion as loud as that of a pistol was perceived; and in the fourth instance, although the platinum top of the rod, which was one hundred and fifty

feet from the surface of the ground, was melted, the discharge was transmitted to the earth without any other effect than a slight inductive shock given to a number of persons standing at the foot of the tower. In three of these cases the peculiar sound we have mentioned was observed;—first, a slight hissing noise, and afterward the loud explosion, as if the former were produced by the effect of the discharge on the air in the immediate vicinity of the rod, and the loud noise from that on the air at a more distant point of its path.

The writer was led to reflect upon this effect of the rod by a remarkable exhibition he witnessed during a thunder-storm at night in 1856. He was in his office, which is in the second story of the main tower of the Smithsonian edifice, when a noise above, as if one of the windows of the tower had been blown in, attracted his attention: an assistant who was present was requested to take his lantern and ascertain what had happened. After an absence for some time he returned, saying he could discover nothing to account for the noise, but that he had heard a remarkable hissing sound. The writer then ascended to the top of the tower, and stood in the open trap-door with his head projecting above the flat roof within about twelve feet of the point of the lightning-rod. No rain was falling, though an intensely black cloud was immediately overhead and apparently at a small elevation; from different parts of this, lightning was continually flashing, indeed the air around the top of the tower itself appeared to be luminous. But the most remarkable appearance was a stream of light three or four feet long issuing with a loud hissing noise from the top of the lightning-rod. It varied in intensity with each flash, and was almost continuous during the observation. Although the whole appearance was highly interesting, and produced a considerable degree of excitement, yet the writer did not deem it prudent to expose himself to the direct or even inductive effect of a discharge under such conditions, thinking as he did with Arago, that however our vanity might prompt us to boast of the acquaintance of some great lords of creation, it is not always desirable to seek their presence or court

much familiarity with them. The effect of the rod in this case on the surrounding air and on the cloud itself by invisible induction must have been quite remarkable.

Action of lightning-rods.—The question as to whether the lightning-rod actually attracts the electricity from a distance has been frequently discussed. "It will be found," says Sir W. Snow Harris, "that the action of a pointed conductor is purely passive. It is rather the patient than the agent; and such conductors can no more be said to attract or invite a discharge of lightning than a water-course can be said to attract the water which flows through it at the time of heavy rain." This statement does not, as it appears to us, present a proper view of the case. From the established principles of induction, it must be evident that all things being equal a pointed rod, though elevated but a few feet above the ground, would be struck in preference to any point on the surface, and the propositions as to the space which can be protected from a discharge of lightning are founded on the supposition that the direction of the discharge can be changed by the action of the rod at a distance and the bolt drawn to itself. The true state of the case appears to us to be as follows:

1st. An elevated pointed rod, erected for example on a high steeple, by its powerful induction diminishes the intensity of the lower part of the cloud, and therefore may lessen the number of explosive discharges to the earth.

2d. If an explosive discharge takes place from the cloud due to any cause whatever, it will be attracted from a giver distance around to the rod, and transmitted innoxiously to the earth.

A too exclusive attention to either one or the other of these actions has led to imperfect views as regards the office of the lightning-rod. On the one hand, some have considered that the whole effect of the rod is to lessen the number of discharges in the way described, and have considered it impossible that an explosive discharge could take place on a pointed conductor. But this is not the case, as was shown by Mr. Wilson many years ago by his experiments

in London. It is true, that when a needle is presented to a charged conductor, the electricity is drawn off silently without an explosion, and this is always the case if sufficient time be allowed for the electricity to escape in this way. But if the point be suddenly brought within striking distance of the conductor by a rapid motion, such as would be produced by the movement of a horizontal arm carrying the point immediately under the conductor in an instant, an explosive discharge will take place. In this case sufficient time is not given for the slower transmission of the electricity by what has been denominated the glowing discharge, and a rupture of the air is produced as in the action of a conductor terminated by a ball.

It would follow from this that in the case of a rapidly-moving cloud across the zenith of a rod, there would be a greater tendency to an explosive discharge on the point than when the cloud was nearly stationary. For a similar reason, if a point connected with the earth by a wire be directed toward an insulated conductor, and the latter be suddenly electrified by a discharge from a second conductor, an explosion will take place between the first conductor and the point. A similar effect would be produced if a lower cloud received a sudden discharge from one above it, a case which probably frequently occurs in nature. Mr. Wise informs us that when a discharge takes place from the base of a cloud to the earth, a discharge is seen to pass between the upper and lower part of the cloud. (A condition shown in Fig. 19.) We are warranted from the foregoing facts, as well as from the numerous examples in which lightning has actually been seen to fall upon pointed rods explosively, and the number of points which have been melted, to conclude that the rod under certain conditions does actually attract the lightning, though when properly constructed it transmits it without disturbance to the earth.

It has been denied by some that the point has any perceptible influence in lessening the number of strokes from a cloud, but this proposition can scarcely be doubted when we reflect upon the fact that it is not necessary to entirely

discharge a cloud in order to prevent a rupture of the air, it being only necessary to draw off a quantity of the fluid sufficient to reduce it just below that which is required to produce the explosion; and for this effect there may be required but a very slight diminution in the intensity of a cloud which is at about the striking distance, to prevent an explosion, particularly when we consider the prodigious number of sparks which during thunder-storms were silently withdrawn from the cloud by the pointed rod erected by Beccaria.

Arago has collected a large number of instances, from which it appears that the erection of a rod lessened the number of the explosive discharges.

The Campanile of St. Marks, at Venice, from the multitude of the pieces of iron in its construction, was in a high degree exposed to danger from lightning, and in fact prior to 1776, had been known to be struck nine times. In the beginning of that year a conductor was placed upon it, and since that time the edifice has been un-injured by lightning.

Previous to 1777, the tower of Sienna was frequently struck, and on every occasion much injured. In that year it was provided with a conductor, and has since received one discharge, but with no damage.

In the case of a church at Carinthia, on an average four or five strokes of lightning annually were discharged upon the steeple until a conductor was erected, after which one stroke was received in five years. At the Valentino palace the lightning conductors established by Beccaria, caused the entire disappearance of strokes of lightning which were previously of frequent occurrence.

The monument in London, although only accidentally provided with a virtual conductor, appears to have been exempt from damage by lightning for nearly one hundred and eighty years.

The action of the rod in diminishing the intensity of the cloud however, can only be of a very temporary character, and cannot, as some have supposed, affect its subsequent state, or disarm it of its fulminating power, since its elec-

tricity is constantly renewed; a fact sufficiently demonstrated by the observation that a thunder storm, through its whole course of several hundred miles in extent, continually gives discharges to the earth. Notwithstanding the instances given by Arago of the diminution of discharges of lightning after the erection of the rod, the fact is established by observation, experiment, and theory, that the rod does attract the lightning, and that it receives the discharge not alone silently, but explosively. The points of the conductors are frequently melted, and although in cases in which this occurs, the discharge passes harmlessly to the earth, yet in some instances the explosion might not have taken place had the rod not been present.

The following instructive illustration of the action of a very elevated conductor in transmitting a discharge from a thunder cloud is furnished us by Mr. Henry J. Rogers, telegraph engineer, who was himself an eye-witness of what he relates:

"In accordance with my promise I will endeavor to give you a brief description of the effect produced by atmospheric electricity at the House Telegraph mast, erected at the Palisades on the west side of the Hudson river, in the vicinity of Fort Lee, New Jersey, and distant about ten miles from the City Hall, New York, during a terrific thunder storm which occurred on Friday, June 17, 1853, between three and four o'clock P. M., while I was on an official visit.

"Before I proceed with the description it will be necessary to explain that the wires of the House and Morse telegraph lines cross the Hudson river between Fort Washington and the Palisades, inasmuch as this is the narrowest part of the river in the vicinity of New York, and the elevation of the land at the Palisades renders it a desirable place for suspending the wires from one shore to the other, so as to allow vessels of large size to pass under them free from interruption.

"The mast to support the wire was 266 feet in length, and was erected on the top of the columnar wall of the Palisades, which at this place is 298 feet above the river, as determined by trigonometrical measurement. The top of the mast was therefore 564 feet above the water, and was sufficiently elevated to allow for the unavoidable sagging of the telegraph wire, and to leave sufficient distance for vessels to pass beneath.

"It was composed of three pieces of heavy timber placed one above the other and fastened together by iron bands, to which were attached long iron braces or guys secured at the lower ends to the rock for the purpose of sustaining the mast in its perpendicular position. The braces or guys were formed of iron rods three-fourths of an inch in diameter, and painted black. The longer or outer ones, (those which were attached to the top of the mast and along which the electricity descended to the earth,) terminated about 32 paces from the lower end of the mast: they were composed of pieces of iron rod of thirteen feet in length, and each piece terminated in a bolt and shackle, thereby forming a series of links 30 in number.

"A lightning-rod six feet long, three-quarters of an inch diameter, painted white, sharpened to a point, but not tipped with platinum, and secured at its lower end to the iron band to which were attached the upper set of guys, projected about two or three feet above the truck of the mast. The point of the rod was at the time in the center of a cedar bush in full foliage which had been placed there by the riggers when they completed the mast.

"At 3 P. M., when the storm commenced, I placed myself in the railway house at Fort Washington, a point distant about three-quarters of a mile from the mast at Fort Lee, on the opposite side of the river. From my position I could distinctly observe the gust as it advanced from the south-west; and from the heat of the weather and appearance of the clouds I expected to witness heavy discharges of atmospheric electricity, and prepared my mind to observe the effects of the storm on the mast at Fort Lee, having frequently expressed a desire to witness a thunder-storm in the vicinity of the mast, as I felt assured the iron rod and guys would protect it from injury.

"As the gale increased the clouds advanced with a heavy atmosphere, and accompanied with frequent discharges of lightning and loud thunder. When it approached the mast the foremost cloud assumed the shape of an inverted cone, (similar to those I have witnessed in the Gulf of Mexico, forming a water-spout;) and I soon observed a terrific flash of lightning descend by the southern iron guy clearly defining its form and every link of the guy as though it were a rod of red-hot iron; and this appearance continued for at least four seconds, followed by three or four heavy peals of thunder in rapid succession, during which time the lightning appeared to flow in a continued stream of

fire along the iron guy, and giving off during its progress apparently as many snaps of electricity as there were links in the guy, and which I supposed to be caused by the resistance offered by each link to the free passage of the electricity.

"These discharges were succeeded by a heavy gush of rain which obstructed my view of the Palisades, but other discharges of atmospheric electricity followed as the cloud rushed on its course along the North river. The storm lasted about half an hour.

"Within 50 paces north of the mast described stood the Morse-line mast, which is about 40 feet less in height than the House mast; and during the storm there was no indication of any part of it being struck by lightning, although there is attached to it a conductor of atmospheric electricity. From this I infer that the discharge of lightning passed to the earth along the iron guys of the House mast, owing to its greater elevation, and to its being more south and thus toward the storm.

"Such was the vividness and intensity of the light which was emitted along the guy at the time of the discharge that I received the impression that the iron was melted, and expected every moment to see the mast prostrated by the wind, but was much surprised on examining the premises next day to find not the least evidence of fusion on the rod, or marks of any kind along its surface to indicate the passage of the electrical discharge.

"The Palisades in the vicinity of the mast are heavily timbered, and although the limbs of several trees are in contact with the iron guys running from the mast, not the slightest damage was done to any of these trees; but about one-fourth of a mile south of the mast a large tree was shattered by lightning during the same storm.

"The mast stood about five years, and during that time, as reported by those having charge of it, was struck at almost every violent thunder-storm that passed over the place. It was considered by persons living in the neighborhood as a protection against lightning.

"Indeed such was the confidence in it that the telegraph workmen did not hesitate to take shelter during a storm in a house 15 feet square which was built around the mast, and in which implements, windlasses, &c., were kept.

"Baltimore, November 30, 1853."

The facts presented in the foregoing narrative are highly

instructive. The descent of the visible vapor in the form of an inverted cone is a phenomenon which will be considered of special interest, particularly by those who ascribe the motive power of a tornado entirely to electricity.

The continuance of the discharge during four seconds is in accordance with other instances which have been frequently observed, and is to be attributed to a series of discharges in rapid succession through the same path.

The appearance of light along the whole course of the rods forming the guy may be attributed to the circumstance that the metal at the time of the discharge was covered with a thin stratum of water into which the electricity was projected by its self-repulsion, and on account of the imperfect conductibility of the liquid, gave rise to the phenomena observed.

This may be illustrated experimentally by discharging an electrical battery through a slip of tin foil wetted with a thin stratum of water. The discharge which would be insensible along the dry metal becomes luminous through its whole course.

While this account of Mr. Rogers clearly shows the attractive power of an elevated conductor under particular circumstances, it also proves the fact that an edifice may be protected from harm, provided it be furnished with a sufficient number of properly constructed rods.

Construction of lightning-rods.—Electricity (as we have seen —page 342,) tends to pass at the surface of a conductor of a sufficient size, but it does not follow from this that every increase of surface, the quantity of metal being the same, will tend to diminish the resistance of the conductor to the passage of a discharge. From an imperfect view of the subject, many persons have supposed that merely flattening the lightning-rod, and thus increasing the surface would tend to increase the conducting power, but it must be evident from the principle of repulsion, that in diminishing the distance between the two flat surfaces, we tend to increase the repulsion between the atoms, which would pass parallel to the axis along the middle of each flat side, and thus, though the

surface is increased by flattening a round bar, the conduction is diminished, and a greater intensity is given to the electricity at the edges, tending to increase the lateral escape of the fluid. The only proper way of diminishing the resistance to conduction in a rod of metal of a given capacity is to mold it into the form of a hollow cylinder; a gas-pipe for example will offer less resistance to conduction than the same weight of metal in the form of a solid cylinder; but we must not infer from this that a gas-pipe an inch in diameter will conduct better than a solid rod of iron of the same diameter. There is no known law of electricity which would lead us to suppose that by removing the metal from the interior of a rod, we increase its conducting capacity. On the contrary when the discharge is very great in proportion to the size of the conductor, it is probable that the discharge penetrates through the entire mass. The rod should be of sufficient size to transmit freely the largest discharge that experience has shown as likely to fall on a building. A rod of three-fourths of an inch of round iron is generally considered sufficient for this purpose, since a conductor of this capacity has in no case been found to have been fused by a discharge from the clouds. There is no objection on the score of electrical action to using a larger bar, or to the same weight of metal in the form of a hollow cylinder; indeed every increase of diameter lessens the resistance to conduction, and the tendency to give off lateral sparks.

Lightning-conductors are frequently constructed in this country with points projecting at intervals of two or three feet through their whole length; this plan has been adopted from some erroneous idea in regard to the action of the conductor, and of the proper application of points. The essential office of the conductor is to receive the discharge from the cloud, and to transmit it with the least resistance possible, silently and innoxiously to the great body of the earth below, and anything which militates against these requisites must be prejudicial. Now in the passage of the electricity through a conductor, it retains its repulsive energy, and hence each point along the rod in succession becomes highly charged, and tends to give off a spark to bodies in the neigh-

borhood. Besides this, the irregularity in the motion of the electricity which is thus produced, must on mechanical principles interfere with its free transmission. Points should therefore be omitted along the course of the rod, since they can do no possible good, and may produce injury.

We may conclude what we have said in regard to lightning-rods by the following summary of directions for constructing and erecting them:

1st. The rod should consist of round iron, of not less than three-fourths of an inch in diameter. A larger size is preferable to a smaller one. Iron is preferred, because it can be readily procured, is cheap, a sufficiently good conductor, and when of the size mentioned cannot be melted by a discharge from the clouds.

2d. It should be, through its whole length, in perfect metallic continuity; as many pieces should be joined together by welding, as practicable, and when other joinings are unavoidable, they should be made by screwing the parts firmly together by a coupling ferule, care being taken to make the upper connection of the latter with the rod water-tight by cement, solder, or paint.

3d. To secure it from rust the rod should be covered with a coating of black paint.

4th. It should be terminated above with a single point, the cone of which should not be too acute, and to preserve it from the weather as well as to prevent melting it should be encased with platinum, formed by soldering a plate of this metal, not less than the twentieth of an inch in thickness, into the form of a hollow cone. Usually the cone of platinum, for convenience, is first attached to a brass socket which is secured on the top of the rod, and to this plan there is no objection. The platinum casing is frequently made so thin and the cone so slender, in order to save metal, that the point is melted by a powerful discharge.

5th. The shorter and more direct the rod is in its course to the earth the better. Acute angles made by bending in the rod and projecting points from it along its course should be avoided.

6th. It should be fastened to the house by iron eyes, and

may be insulated by cylinders of glass. We do not think the latter however of much importance since they soon become wet by water, and in case of a heavy discharge are burst asunder.

7th. The rod should be connected with the earth in the most perfect manner possible, and in cities nothing is better for this purpose than to unite it in good metallic contact with the gas mains or large water pipes in the streets; and such a connection is absolutely necessary if the gas or water pipes are in use within the house. This connection can be made by soldering to the end of the rod a strip of copper, which, after being wrapped several times around the pipe, is permanently attached to it. Where a connection with the ground cannot be formed in this way the rod should terminate, if possible, in a well always containing water, and where this arrangement is not practicable it should terminate in a plate of iron or some other metal buried in the moist ground. Before it descends into the earth, it should be bent so as to pass off nearly perpendicular to the side of the house, and it should be buried in a trench, surrounded with powdered charcoal.

8th. The rod should be placed, in preference, on the west side of the house, in this latitude, and especially on the chimney from which a current of heated air ascends during the summer season.

9th. In case of a small house a single rod may suffice, provided its point be sufficiently high above the roof, the rule being observed that its elevation should be at least half of the distance to which its protection is expected to extend. It is safer however, particularly in modern houses in which a large amount of iron enters into the construction, to make the distance between two rods less than this rule would indicate rather than more. Indeed we see no objection to an indefinite multiplication of rods to a house, provided they are all properly connected with the ground and with each other. A building entirely enclosed, as it were, in a case of iron rods so connected with the earth would be safe from the direct action of the lightning.

10th. When a house is covered by a metallic roof the latter

should be united in good metallic connection with the lightning-rods; and in this case the perpendicular pipes conveying the water from the gutters at the eaves may be made to act the part of rods by soldering strips of copper to the metal roof and pipes above, and connecting them with the earth by plates of metal united by similar strips of copper to their lower ends, or better with the gas or water pipes of the city. In this case however the chimneys would be unprotected, and copper lightning-rods soldered to the roof and rising a few feet above the chimneys would suffice to receive the discharge. We say soldered to the roof, because if the contact were not very perfect, a greater intensity of action would take place at this point, and the metal might be burnt through by the discharge, particularly if it were thin.

11th. As a general rule large masses of metal within the building, particularly those which have a perpendicular elevation, ought to be connected with the rod. The main portion of the great building erected for the world's exhibition at Paris is entirely surrounded by a rod of iron from which rises at intervals a series of lightning conductors, the whole system being connected with the earth by means of four wells, one at each corner of the edifice.

The foregoing rules may serve as general guides for the erection of lightning-rods on ordinary buildings, but for the protection of a large complex structure, consisting of several parts, a special survey should be made, and the best form of protection devised which the peculiar circumstances of the case will admit.

Numerous patents have been obtained in this country for improved lightning conductors, but as a general rule such improvements are of little importance.

Such assumed improvements on the form of the lightning-rod recommended by the French Academy in 1823 would pre-suppose some important discoveries in electricity having a bearing on the subject; but after the lapse of thirty years the same Academy being called upon to consider the protection of the new additions to the Louvre finds nothing material to change in the principles of the instructions at first given.

ON ACOUSTICS APPLIED TO PUBLIC BUILDINGS.

(Proceedings American Association Adv. of Science, vol. x, pp. 119–135.)

August 22, 1856.

At the meeting of the American Association in 1854, I gave a verbal account of the plan of a lecture-room adopted for the Smithsonian Institution, with some remarks on acoustics as applied to apartments intended for public speaking.* At that time the room was not finished, and experience had not proved the truth of the principles on which the plan had been designed. Since then the room has been employed two winters for courses of lectures to large audiences; and I believe it is the general opinion of those who have been present, that the arrangements for seeing and hearing, considering the size of the apartment, are entirely unexceptionable. The room has fully answered all the expectations which were formed in regard to it, previous to its construction. The origin of the plan was as follows:

Professor Bache and myself had directed our attention to the subject of acoustics as applied to buildings, and had studied the peculiarities in this respect of the hall of the House of Representatives, when the President of the United States referred to us for examination the plans proposed by Captain M. C. Meigs of the Engineer Corps, U. S. A., for the rooms about to be constructed under his direction in the new wings of the Capitol. After visiting with Captain Meigs the principal halls and churches of the cities of Philadelphia, New York, and Boston, we reported favorably on the general plans proposed by him, and which were subsequently adopted.

The facts we have collected on this subject may be referred to a few well-established principles of acoustics, which have

* ["On the Arrangement of Lecture Rooms, with reference to Sound and Sight."—Proceedings of the American Association for the Advancement of Science, May, 1854; vol. VIII, p. 106. Only the title published.]

been applied in the construction of the Smithsonian lecture-room. To apply them generally however in the construction of public halls, required a series of preliminary experiments.

In a small apartment it is an easy matter to be heard distinctly at every point; but in a large room, unless provision be made in the original plan of the building for a suitable arrangement, on acoustic principles, it will be difficult, and indeed in most cases impossible, to produce the desired effect. The same remark may be applied to the lighting, heating, and ventilation, and to all the special purposes to which a particular building is to be applied. I venture therefore to make some preliminary remarks on the architecture of buildings, bearing upon this point, which, though they may not meet with universal acceptance, will I trust commend themselves to the common sense of the public in general.

Architectural limitations.—In the erection of a building, the uses to which it is to be applied should be clearly understood, and provision definitely made, in the original design, for every desired object.

Modern architecture is not, like painting or sculpture, a fine art, *par excellence.* The object of these latter is to produce a moral emotion,—to awaken the feelings of the sublime and the beautiful; and we greatly err when we apply their productions to a merely utilitarian purpose. To make a fire-screen of Rubens' Madonna, or a candelabrum of the Apollo Belvidere, would be to debase those exquisite productions of genius, and do violence to the feelings of the cultivated lover of art. Modern buildings are made for other purposes than artistic effect, and in them the æsthetical must be subordinate to the useful; though the two may co-exist, and an intellectual pleasure be derived from a sense of adaptation and fitness, combined with a perception of harmony of parts, and the beauty of detail.

The buildings of a country and an age should be ethnological expressions of the wants, habits, arts, and feelings of the time in which they were erected. Those of Egypt,

Greece, and Rome were intended (at least in part) to transmit to posterity, without the art of printing, an impression of the character of the periods in which they were erected. It was by their monuments that these nations sought to convey to future ages an idea of their religious and political sentiments.

The Greek architect was untrammelled by any condition of utility. Architecture was with him in reality a fine art. The temple was formed to gratify the tutelar deity. Its minutest parts were exquisitely finished, since nothing but perfection on all sides and in the smallest particulars could satisfy an all-seeing and critical eye. It was intended for external worship, and not for internal use. It was without windows, entirely open to the sky, or if closed with a roof, the light was merely admitted through a large door. There were no arrangements for the heating or ventilation. The uses therefore to which buildings of this kind can be applied in modern times are exceedingly few; and though they were objects of great beauty, and fully realized the intention of the architect by whom they were constructed, yet they cannot be copied in our day without violating the principles which should govern architectural adaptation.

Every vestige of ancient architecture which now remains on the face of the earth should be preserved with religious care; but to servilely copy these, and to attempt to apply them to the uses of our day, is as preposterous as to endeavor to harmonize the refinement and civilization of the present age with the superstition and barbarity of the times of the Pharaohs. It is only when a building expresses the dominant sentiment of an age, when a perfect adaptation to its use is joined to harmony of proportions and an outward expression of its character, that it is entitled to our admiration. It has been aptly said, that it is one thing to *adopt* a particular style of architecture, but a very different one to *adapt* it to the purpose intended.

Architecture should change not only with the character of the people, and in some cases with the climate, but also with the material to be employed in construction. The use

of iron and of glass requires an entirely different style from that which sprung from the rocks of Egypt, the masses of marble with which the lintels of the Grecian temples were formed, or the introduction of brick by the Romans.

The great tenacity of iron, and its power of resistance to crushing, should suggest for it, as a building material, a far more slender and apparently lighter arrangement of parts. An entire building of iron, fashioned in imitation of stone, might be erected at small exercise of invention on the part of the architect, but would do little credit to his truthfulness or originality. The same may be said of our modern pasteboard edifices, in which, with their battlements, towers, pinnacles, "fretted roofs and long drawn aisles," cheap and transient magnificence is produced by painted wood or decorated plaster.

Lecture-room Acoustics.—To return to the subject of acoustics, as applied to apartments intended for public speaking: While sound, in connection with its analogies to light, and in its abstract principles, has been investigated within the last fifty years with a rich harvest of results, few attempts have been successfully made to apply these principles to practical purposes. Though we may have a clear conception of the simple operation of a law of nature, yet when the conditions are varied, and the actions multiplied, the results frequently transcend our powers of logic, and we are obliged to appeal to experiment and observation to assist in deducing new consequences, as well as to verify those which have been arrived at by mathematical deduction. Furthermore, though we may know the manner in which a cause acts to produce a given effect, yet in all cases we are obliged to resort to actual experiment to ascertain the measure of effect under given conditions.

The science of acoustics as applied to buildings, perhaps more than any other, requires this union of scientific principles with experimental deductions. While on the one hand, the application of simple deductions from the established principles of acoustics would be unsafe from a want of knowledge of the constants which enter into our formulæ,

on the other hand empirical data alone are in this case entirely at fault, and of this any person may be convinced who will examine the several works written on acoustics by those who are deemed practical men.

Sound is a motion of matter capable of affecting the ear with a sensation peculiar to that organ. It is not in all cases a motion simply of the air, for there are many sounds in which the air is not concerned; for example, the impulses which are conveyed along a rod of wood from a tuning-fork to the teeth. When a sound is produced by a single impulse, or an approximation to a single impulse, it is called a noise; when by a series of impulses, a continued sound, &c.; if the impulses are equal in duration among themselves, a musical sound. This has been illustrated by a quill striking against the teeth of a wheel in motion. A single impulse from one tooth is a noise, from a series of teeth in succession a continued sound; and if all the teeth are at equal distances, and the velocity of the wheel is uniform, then a musical note is the result. Each of these sounds is produced by the human voice, though they apparently run into each other. In speaking however a series of irregular sounds of short duration is usually emitted,—each syllable of a word constitutes a separate sound of appreciable duration, and each compound word and sentence an assemblage of such sounds. It is no little surprising that in listening to a discourse, the ear can receive so many impressions in the space of a second, and that the mind can take cognizance of and compare them.

That a certain force of impulse and a certain time for its continuance are necessary to produce an audible impression on the ear, is evident, but it may be doubted whether the impression of a sound on this organ is retained appreciably longer than the continuance of the impulse itself, certainly it is not retained the $\frac{1}{10}$th of a second. If this were the case it is difficult to conceive why articulated discourse, which so pre-eminently distinguishes man from the lower animals, should not fill the ear with a monotonous hum; but whether the ear continues to vibrate, or whether the impression re-

mains a certain time on the sensorium, it is certain that no sound is ever entirely instantaneous, or the result of a single impression, particularly in enclosed spaces. The impulse is not only communicated to the ear but to all bodies around, which in turn become themselves centres of reflected impulses. Every impulse must give rise to a forward and afterward a backward motion of a small portion of the medium.

Sound from a single explosion in air equally elastic on all sides tends to expand equally in every direction; but when the impulse is given to the air in a single direction, though an expansion takes place on all sides, yet it is much more intense in the line of the impulse. For example, the impulse of a single explosion, like that of the detonation of a bubble of oxygen and hydrogen, is propagated equally in all directions, while the discharge of a cannon, though heard on every side, is much louder in the direction of the axis; so also a person speaking is heard much more distinctly directly in front than at an equal distance behind. Many experiments have been made on this point, and I may mention those repeated in the open space in front of the Smithsonian Institution. In a circle 100 feet in diameter, the speaker in the centre, and the hearer in succession at different points of the circumference, the voice was heard most distinctly directly in front, gradually less so on either side, until in the rear it was scarcely audible. The ratio of distance for distinct hearing directly in front, on the sides, and in the rear was about as 100, 75, and 30. These numbers may serve to determine the form in which an audience should be arranged in an open field in order that those on the periphery of the space may all have a like favorable opportunity of hearing, though such a disposition should not be recommended as the form of an apartment where a reflecting wall would be behind the speaker.

The impulse producing sound requires time for its propagation, and this depends upon the intensity of repulsion between the atoms, and secondly, on the specific gravity of the matter itself. If the medium were entirely rigid sound

would be propagated instantaneously; the weaker the repulsion between the atoms the greater will be the time required to transmit the motion from one to the other; and the heavier the atoms the greater will be the time required for the action of a given force to produce in them a given amount of motion. Sound also, in meeting an object, is reflected in accordance with the law of light, making the angle of incidence equal to the angle of reflection. The tendency however to divergency in a single beam of sound appears to be much greater than in the case of light. The law nevertheless appears to be definitely followed in the case of all beams that are reflected in a direction near the perpendicular. It is on the law of propagation and reflection of sound that the philosophy of an echo depends. Knowing the velocity of sound it is an easy matter to calculate the interval of time which must elapse between the original impulse and the return of the echo. Sound moves at the rate of 1125 feet in a second at the temperature of 60°.

If therefore we stand at half this distance before a wall, the echo will return to us in one second. It is however a fact known from universal experience that no echo is perceptible from a near wall, though in all cases one must be sent back to the ear. The reason of this is that the ear cannot distinguish the difference between similar sounds, as for example, that from the original impulse and its reflection if they follow each other at less than a given interval, which can only be determined by actual experiment, and as this is an important element in the construction of buildings the attempt was made to determine it with some considerable degree of accuracy. For this purpose the observer was placed immediately in front of the wall of the west end of the Smithsonian building at the distance of 100 feet; the hands were then clapped together. A distinct echo was perceived; the difference between the time of the passage of the impulse from the hand to the ear, and that from the hand to the wall and back to the ear, was sufficiently great to produce two entirely distinct impressions. The observer then gradually approached the building until no echo or perceptible pro-

longation of the sound was observed. By accurately measuring this distance and doubling it we find the interval of space within which two sounds may follow each other without appearing separately. But if two rays of sound reach the ear after having passed through distances the difference between which is greater than this, they produce the effect of separate sounds. This distance we have called the *limit of perceptibility* in terms of space. If we convert this distance into the velocity of sound, we ascertain the limit of perceptibility in time.

In the experiment first made with the wall a source of error was discovered in the fact that a portion of the sound returned was reflected from the cornice under the eaves, and as this was at a greater distance than the part of the wall immediately perpendicular to the observer the moment of cessation of the echo was less distinct. In subsequent experiments with a louder noise, the reflection was observed from a perpendicular surface of about 12 feet square, and from this more definite results were obtained. The limit of the distance in this case was about 30 feet, varying slightly perhaps with the intensity of the sound and the acuteness of different ears. This will give about the sixteenth part of a second as the limit of time necessary for the ear to separately distinguish two similar sounds. From this experiment we learn that the reflected sound may tend to strengthen the impression, or to confuse it, according as the difference of time between the two impressions is greater or less than the limit of perceptibility. An application of the same principle gives us the explanation of some phenomena of sound which have been considered mysterious. Thus, in the reflection of an impulse from the edge of a forest of trees each leaf properly situated within a range of 30 feet of the front plane of reflection will conspire to produce a distinct echo, and these would form the principal part of the reflecting surfaces of a dense forest, for the remainder would be screened; and being at a greater distance, any ray which might come from them would serve to produce merely a low continuation of the sound.

On the same principle we may at once assert that the panelling of a room, or even the introduction of reflecting surfaces at different distances will not prevent the echo, provided they are in parallel planes, and situated relatively to each other within the limit of perceptibility.

Important advantage may be taken of the principle of reflection of sound by a proper arrangement of the reflecting surfaces behind the speaker. We frequently see in churches, as if to diminish the effect of the voice of the preacher, a mass of drapery placed directly in the rear of the pulpit. However satisfactory this may be in an æsthetical point of view, it is certainly at variance with correct acoustic arrangements, the great object of which should be to husband every articulation of the voice, and to transmit it unmingled with other impulses and with as little loss as possible to the ears of the audience.

Another effect of the transmission and reflection of sound is that which is called reverberation, which consists of a prolonged musical sound, and is much more frequently the cause of indistinctness of perception of the articulations of the speaker than the simple echo.

Reverberation is produced by the repeated reflection of a sound from the walls of the apartment. If for example a single detonation takes place in the middle of a long hall with naked and perpendicular walls, an impulse will pass in each direction, will be reflected from the walls, cross each other again at the point of origin, be again reflected, and so on until the original impulse is entirely absorbed by the solid materials which confine it. The impression will be retained upon the ear during the interval of the transmission past it of two successive waves, and thus a continued sound will be kept up, particularly if the walls of any part of the room are within 30 feet of the ear. If a series of impulses, such as that produced by the rapid snaps of a quill against the teeth of a wheel be made in unison with the echoes, a continued musical sound will be the result. Suppose the wheel to be turned with such velocity as to cause a snap at the very instant the return echo passes the point

at which the apparatus is placed, the second sound will combine with the first, and thus a loud and sustained vibration will be produced. It will be evident from this that every room has a key-note, and that to an instrument of the proper pitch it will resound with great force. It must be apparent also, that the continuance of a single sound and the tendency to confusion in distinct perception, will depend on several conditions;—first, on the size of the apartment; secondly, on the strength of the sound or the intensity of the impulse; thirdly, on the position of the reflecting surfaces; and fourthly, on the nature of the material of the reflecting surfaces.

In regard to the first of these, the larger the room the longer time will be required for the impulse along the axis to reach the wall; and if we suppose that at each collision a portion of the original force is absorbed, it will require double the time to totally extinguish it in a room of double the size, because, the velocity of sound being the same, the number of collisions in a given time will be inversely as the distance through which the sound has to travel.

Again, that it must depend upon the loudness of the sound or the intensity of the impulse, must be evident, when we consider that the cessation of the reflections is due to the absorption by the walls, or to irregular reflection, and that consequently the greater the amount of original disturbance the longer will be the time required for its complete extinction. This principle was abundantly shown by our observations on different rooms.

Thirdly, the continuance of the resonance will depend upon the position of the reflecting surfaces. If these are not parallel to each other, but oblique, so as to reflect the sound not to the opposite but to the adjacent wall, without passing through the longer axis of the room, it will evidently be sooner absorbed. Any obstacle, also, that may tend to break up the wave and interfere with the reflection through the axis of the room will serve to lessen the resonance of the apartment. Hence, though the panelling, the ceiling, and the introduction of a variety of oblique surfaces, may not pre-

vent an isolated echo, provided the distance be sufficiently great and the sound sufficiently loud, yet that they do have an important effect in stopping the resonance is evident from theory and experiment. In a room 50 feet square in which the resonance of a single intense sound continued six seconds, when cases and other objects were placed around the wall its continuance was reduced to two seconds.

Fourthly, the duration of the resonance will depend upon the nature of the material of the wall. A reflection always takes place at the surface of a new medium, and the amount of this will depend upon the elastic force or power to resist compression and the density of the new medium. For example, a wall of nitrogen, if such could be found, would transmit nearly the whole of a wave of sound in air, and reflect but a very small portion; a partition of tissue-paper would produce nearly the same effect. A polished wall of steel however, of sufficient thickness to prevent yielding, would reflect for practical purposes all the impulses through the air which might fall upon it. The rebound of the wave is caused, not by the oscillation of the wall, but by the elasticity and mobility of the air. The striking of a single ray of sound against a yielding board would probably increase the loudness of the reverberation but not its continuance. On this point a series of experiments was made by the use of the tuning-fork. In this instrument the motion of the foot and of the two prongs gives a sonorous vibration to the air, which, if received upon another tuning-fork of precisely the same size and form, would re-produce the same vibrations.

It is a fact well established by observation that when two bodies are in perfect unison, and separated from each other by a space filled with air, vibrations of the one will be taken up by the other. From this consideration it is probable that relatively the same effect ought to be produced in transmitting immediately the vibration of a tuning-fork to a reflecting body as to duration and intensity as in the case of transmission through air. This conclusion is strengthened by floating a flat piece of wood on water in a vessel standing

upon a sounding-board; placing a tuning-fork on the wood the vibrations will be transmitted to the board through the water, and sounds will be produced of the same character as those emitted when the tuning-fork is placed directly upon the board.

A tuning-fork suspended from a fine cambric thread and vibrated in air was found, from the mean of a number of experiments, to continue in motion 252 seconds. In this experiment, had the tuning-fork been in a perfect vacuum suspended without the use of a string, and further, had there been no ætherial medium, the agitation of which would give rise to light, heat, electricity, or some other form of ætherial motion, the fork would have continued its vibration forever.

The fork was next placed upon a large, thin pine board—the top of a table. A loud sound in this case was produced which continued less than *ten* seconds. The whole table as a system was thrown into motion, and the sound produced was as loud on the under side as on the upper side. Had the tuning-fork been placed against a partition of this material a loud sound would have been heard in the adjoining room; and this was proved by sounding the tuning-fork against a door leading into a closed closet. The sound within was apparently as loud as that without.

The rapid decay of sound in this case was produced by so great an amount of the motive power of the fork being communicated to a large mass of wood. The increased sound was due to the increased surface. In other words the shortness of duration was compensated for by the greater intensity of effect produced.

The tuning-fork was next placed upon a circular slab of marble about three feet in diameter and three-quarters of an inch thick. The sound emitted was feeble, and the undulations continued *one hundred and fifteen* seconds, as deduced from the mean of six experiments.

In all these experiments, except the one in a vacuum, the time of the cessation of the motion of the tuning-fork was determined by bringing the mouth of a resounding cavity

near the end of the fork, this cavity having previously been adjusted to unison with the vibrations of the fork, gave an audible sound when none could be heard by the unaided ear.

The tuning-fork was next placed upon a cube of India-rubber, and this upon the marble slab. The sound emitted by this arrangement was scarcely greater than in the case of the tuning-fork suspended from the cambric thread, and from the analogy of the previous experiments, we might at first thought suppose the time of duration would be great, but this was not the case. The vibrations continued only about forty seconds. The question may here be asked, What became of the impulses lost by the tuning-fork? They were neither transmitted through the India-rubber nor given off to the air in the form of sound, but were probably expended in producing a change in the matter of the India-rubber, or were converted into heat, or both. Though the inquiry did not fall strictly within the line of this series of investigations, yet it was of so interesting a character in a physical point of view to determine whether heat was actually produced that the following experiment was made.

A cylindrical piece of India-rubber about an inch and a quarter in diameter was placed in a tubulated bottle with two openings, one near the bottom and the other at the top. A stuffing-box was attached to the upper opening, through which a metallic stem with a circular foot to press upon the India-rubber was made to pass air-tight. The lower opening was closed with a cork, in a perforation of which a fine glass tube was cemented. A small quantity of red ink was placed in the tube to serve as an index. The whole arrangement thus formed a kind of air-thermometer, which would indicate a certain amount of change of temperature in the enclosed air. On the top of the stem the tuning-fork was screwed, and consequently its vibrations were transmitted to the rubber within the bottle. The glass was surrounded with several coatings of flannel to prevent the influence of external temperature. The tuning-fork was then sounded, and the vibrations were kept up for some time. No reliable indications

of an increase of temperature were observed. A more delicate method of making the experiment next suggested itself. The tube containing the drop of red ink, with its cork, was removed, and the point of a compound wire formed of copper and iron was thrust into the substance of the rubber, while the other ends of the wire were connected with a delicate galvanometer. The needle was suffered to come to rest, the tuning-fork was then vibrated, and its impulses transmitted to the rubber. A very perceptible increase of temperature was the result. The needle moved through an arc of from one to two and a half degrees. The experiment was varied and many times repeated; the motions of the needle were always in the same direction, namely, in that which was produced when the point of the compound wire was heated by momentary contact with the fingers. The amount of heat generated in this way however is small, and indeed in all cases in which it is generated by mechanical means the amount evolved appears very small in comparison with the labor expended in producing it. Joule has shown that the mechanical energy generated in a pound weight by falling through a space of seven hundred and fifty feet elevates the temperature of a pound of water one degree.

It is evident that an object like India-rubber actually destroys a portion of the sound, and hence in cases in which entire non-conduction is required this substance can probably be employed with perfect success.

The tuning-fork was next pressed upon a solid brick wall, and the duration of the vibration from a number of trials was eighty-eight seconds. Against a wall of lath and plaster the sound was louder and continued only eighteen seconds.

From these experiments we may infer that if a room were lined with a wainscot of thin boards and a space left between the wall and the wood, the loudness of the echo of a single noise would be increased while the duration of the resonance would be diminished. If however the thin board were glued or cemented in solid connection to the wall, or embedded in the mortar, then the effect would be a feeble echo and a long continued resonance, similar to that from the

slab of marble. This was proved by first determining the length of continuance of the vibrations of a tuning-fork on a thin board, which was afterwards cemented to a flat piece of marble.

A series of experiments was next commenced with reference to the actual reflection of sound. For this purpose a parabolic mirror was employed, and the sound from a watch received on the mouth of a hearing-trumpet furnished with a tube for each ear. The focus was near the apex of the parabola, and when the watch was suspended at this point it was six inches within the plane of the outer circle of the mirror. In this case the sound was confined at its origin, and prevented from expanding. No conjugate focus was produced, but on the contrary the rays of light, when a candle was introduced, constantly diverged. The ticking of the watch could not be heard at all when the ear was applied to the outside of the mirror, while directly in front it was distinctly heard at the distance of thirty feet, and with the assistance of the ear trumpet at more than double that distance. When the watch was removed from the focus the sound ceased to be audible. This method of experimenting admits of considerable precision, and enables us to directly verify, by means of sound transmitted through air, the results anticipated in the previous experiments. A piece of tissue-paper placed within the mirror and surrounding the watch without touching it, slightly diminished the reflection. A single curtain of flannel produced a somewhat greater effect, though the reflecting power of the metallic parabola was not entirely masked by three thicknesses of flannel; and I presume very little change would have been perceived had the reflector been lined with flannel glued to the surface of the metal. The sound was also audible at the distance of ten feet when a large felt hat without stiffening was interposed between the watch and the mirror. Care was taken in these experiments so to surround the watch that no ray of sound could pass *directly* from it to the reflecting surface.

With a cylindrical mirror, having a parabolic base, very little increased reflection was perceived. The converging

beams in this case were merely in a single plane, perpendicular to the mirror, and passing through the ear, while to the focal point of the spherical mirror a solid cone of rays was sent.

The reflection from the cylindrical mirror forms what is called a *caustic* in optics, while that from a cylindrical mirror gives a true focus, or in other words collects the sounds from all parts of the surface and conveys them to one point of space. These facts furnish a ready explanation of the confusion experienced in the Hall of Representatives, which is surmounted by a dome, the under surface of which acts as an immense concave mirror, reflecting to a focus every sound which ascends to it, leaving other points of space deficient in sonorous impulses.

Water, and all liquids which offer great resistance to compression, are good reflectors of sound. This may be shown by the following experiment. When water is gradually poured into an upright cylindrical vessel, over the mouth of which a tuning-fork is vibrated, until it comes within a certain distance of the mouth, it will reflect an echo in unison with the vibration of the fork, and produce a loud resonance. This result explains the fact, which had been observed with some surprise, that the duration of the resonance of a newly plastered room was not perceptibly less than that of one which had been thoroughly dried.

There is another principle of acoustics which has a bearing on this subject. I allude to the refraction of sound. It is well known that when a ray of sound passes from one medium to another a change in velocity takes place, and consequently a change in the direction or a refraction must be produced. The amount of this can readily be calculated where the relative velocities are known. In rooms heated by furnaces, and in which streams of heated air pass up between the audience and speaker, a confusion has been supposed to be produced and distinct hearing interfered with by this cause. Since the velocity of sound in air at 32° of Fahrenheit has been found to been 1090 feet in a second, and since the velocity increases 1·14 feet for every degree of

Fahrenheit's scale, if we know the temperature of the room and that of the heated current the amount of angular refraction can be ascertained. But since the ear does not readily judge of the difference of direction of two sounds emanating from the same source, and since two rays do not confuse the impression which they produce upon the ear though they arrive by very different routes, provided they are within the limit of perceptibility, we may conclude that the indistinctness produced by refraction is comparatively little. Professor Bache and myself could perceive no difference in distinctness in hearing, from rays of sound passing over a chandelier of the largest size in which a large number of gas jets were in full combustion. The fact of disturbance from this cause however, (if any exist,) may best be determined by the experiment with a parabolic mirror and the hearing-trumpet before described.

These researches might be much extended; they open a field of investigation equally interesting to the lover of abstract science and to the practical builder; and I hope, on behalf of the committee, to give some further facts with regard to this subject at another meeting.

The Smithsonian Lecture-room.—I shall now briefly describe the lecture-room of the Smithsonian Institution, which has been constructed in accordance with the facts and principles previously stated, so far at least as they could be applied.

There was another object kept in view in the construction of this room besides the accurate hearing, namely the distinct seeing. It was desirable that every person should have an opportunity of seeing the experiments which might be performed, as well as of distinctly hearing the explanation of them.

By a fortunate co-incidence of principles, it happens that the arrangements for insuring unobstructed sight do not interfere with those necessary for distinct hearing.

The law of Congress authorizing the establishment of the Smithsonian Institution directed that a lecture-room should be provided; and accordingly in the first plan one-half of the first story of the main building was devoted to this pur-

pose. It was found impossible however to construct a room on acoustic principles in this part of the building, which was necessarily occupied by two rows of columns. The only suitable place which could be found was therefore on the second floor. The main building is two hundred feet long and fifty feet wide; but by placing the lecture room in the middle of the story a greater width was obtained by means of the projecting towers.

The main gallery is in the form of a horse-shoe occupying three sides of the room. The speaker's platform is placed between two oblique walls. The corners of the room which are cut off by these walls afford recesses for the stairs into the galleries. The opposite corners are also partitioned off so as to afford recesses for the same purpose.

The general appearance of the room is somewhat fan-shaped, and the speaker is placed in the mouth as it were of an immense trumpet. The sound directly from his voice and that from reflection immediately behind him is thrown forward upon the audience; and as the difference of distance travelled by the two rays is much within the limit of perceptibility no confusion is produced by direct and reflected sound.

Again, on account of the oblique walls behind the speaker and the multitude of surfaces, including the gallery, pillars, stair-screens, &c., as well as the audience, directly in front, all reverberation is stopped.

The walls behind the speaker are composed of lath and plaster, and therefore have a tendency to give a more intense though less prolonged sound than if of solid masonry. They are also intended for exhibiting drawings to the best advantage.

The seats are arranged in curves and were intended to rise in accordance with the *panoptic curve,* originally proposed by Professor Bache, which enables each individual to see over the head of the person immediately in front of him. The original form of the room however did not allow of this intention being fully realized, and therefore the rise is somewhat less than the curve would indicate.

The ceiling is twenty-five feet high, and therefore within the limit of perceptibility. It is perfectly smooth and unbroken with the exception of an oval opening nearly over the speaker's platform through which light is admitted.

No echo is given off from the ceiling, while this assists the hearing in the gallery by the reflection to that place of the oblique rays.

The architecture of this room is due to Captain B. S. Alexander, of the corps of Topographical Engineers. He fully appreciated all the principles of sound which I have given, and varied his plans until all the required conditions as far as possible were fulfilled.

ACCOUNT OF A LARGE SULPHURIC-ACID BAROMETER IN THE HALL OF THE SMITHSONIAN INSTITUTION.

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The opinion has been frequently advanced that a barometer in which the material used to balance the pressure of the atmosphere is of less specific gravity than mercury, and consequently of a wider range of fluctuation, might throw some new light on several important points of meteorology. The fluid usually proposed for this purpose has been oil or water, the viscid character of the former and its tendency to a change of condition has induced a preference for the latter. Several water-barometers have accordingly been constructed; but as far as I am informed, the indications of the instruments have not been reliable.

Mariotte used one of this character; also Otto von Guericke constructed a philosophical toy to which he gave the name of aëroscope, on the principle of a water-barometer. It consisted of a tube more than thirty feet high elevated on a long wall and terminated by a tall and rather wide glass cylinder hermetically sealed, in which was placed a toy in the shape of a man. All the tube except a portion of

the cylindrical part was concealed behind the wainscoting, and consequently the little image made its appearance only in fine weather.

A water-barometer was constructed by Professor Daniell, and placed in the hall of the Royal Society, of which a full account has been published in the Transactions of that institution. A minute account is given of the method of blowing the tube, and the details of permanently fastening it in the box which was to form the case. The tube was left open at both ends; to the upper one a stop-cock was attached, and the lower one was inserted in a small steam boiler, which served the purpose of boiling the water to expel all the air, of elevating it to the proper height by means of the elastic force of the steam, and also as a permanent cistern to the barometer. After the water was forced to the top and issued from the stop-cock in a jet, the latter was closed; the stop-cock in the boiler was opened, steam suffered to escape, and the water to settle in the tube until balanced by the pressure of air. The upper part of the glass under the stop-cock, (which had previously been drawn out into a fine tube,) was gradually heated by a blow-pipe, and as soon as it was sufficiently softened the pressure of the air effectually closed it. The part above the stop-cock was then removed with a file. This barometer was completed, after adjusting the scale, by pouring a quantity of castor-oil on the surface of the water to prevent contact with the air.

After a series of observations however it was found in the course of about three months that the column of water was gradually descending, and it was finally resolved to open the boiler and to examine the instrument. The oil upon the surface was found to have undergone a change, though the water below was perfectly bright and transparent. A portion of the water was taken out and placed under the receiver of an air-pump, and bubbles of air in abundance were extricated; the air was absorbed by the water, diffused through the whole mass to the top, where it was given off to the vacuum, and thus caused the gradual descent of the column. It was found however that it was not atmospheric air in the

vacuum, but nearly pure nitrogen: the oxygen had been absorbed in passing through the oil, producing rancidity and other changes in that liquid.

It was evident from this experiment that oil was not impervious to air. Another attempt to remedy this defect of the instrument was made by using a thin film of gutta-percha, to be left after the evaporation of the naptha in which it had been dissolved.

An objection however to the use of water as the liquid for the barometer is the vapor which it always gives off, and of which the tension cannot readily be determined. In a glass vessel in which a cup of water is enclosed, Professor Espy informs me that he has found the dew-point always less than that which would be due to the temperature.

Desiring to fit up a barometer on a large scale as one of the objects of interest and use in the Smithsonian Institution, I consulted my friend Professor G. C. Schaeffer of the Patent Office, as to the best liquid to be employed. He advised the use of sulphuric acid, but I did not immediately adopt his advice on account of the apparently dangerous character of this substance. Happening however some time afterwards to be speaking on the subject of barometers with Mr. James Green, the instrument-maker, in the presence of Professor Ellet, of New York, the latter asked why I did not have a large one constructed with sulphuric acid. The suggestion having thus again been independently made, and Mr. Green expressing his willingness to undertake the work, I gave the order for the construction of the instrument, and requested Professor Ellet to give any suggestions as to the details which might be required.

The advantages of this liquid are: 1. That it gives off no appreciable vapor at any atmospheric temperature; and 2. That it does not absorb or transmit air. The objections to its use are: 1. The liability to accident from the corrosive nature of the liquid, either in the filling of the tube or in its subsequent breakage; and 2. Its affinity for moisture, which tends to produce a change in specific gravity. The filling however is a simple process and attended with but little if

any risk. The acid can gradually be poured into the tube while in its case, slightly inclined to the horizon. Any accident from breakage can be prevented by properly securing the whole instrument in an outer case, which will also serve to equalize the temperature. To prevent the absorption of moisture the air may be previously passed through a drying tube apparatus. The only point in which water would be preferable to sulphuric acid is the less specific gravity of the former, and consequently the greater range of its fluctuation, which is as 20 : 11, nearly.

The general appearance of the instrument and the several contrivances for adjustment and reading are in accordance with the reputation of the skillful and intelligent artizan who made it. The glass tube is two hundred and forty inches long and three-fourths of an inch in diameter, and is enclosed in a cylindrical brass case of the same length, and two and a half inches in diameter. The glass tube is secured in the axis of the brass case by a number of cork collars placed at intervals; which, while they prevent all lateral displacement of the tube, allow it to be moved upward and downward for the adjustment of the zero-point.

The reservoir consists of a cylindrical glass bottle of four inches in diameter with two openings at the top; one in the axis to admit the lower end of the long tube, which is tapered to about one-half of the general diameter, the other to transmit the varying pressure of the atmosphere.

To adjust the zero-point the whole glass part of the apparatus together with the contained acid is elevated or depressed by a screw placed under the bottom, until the level of the acid in the reservoir coincides with a fixed mark.

The scale for reading the elevation is divided into inches and tenths, and by means of a vernier, moved by a rack and pinion, the variations can be measured to the hundredth of an inch, and estimated to a still smaller division.

The vernier itself is not immediately attached to the cylindrical brass case, but to a sliding frame which can be moved along the whole opening through which the entire range of the column is observed. The motion of the frame

enables us to make the first rough adjustment, and that of the rack and pinion the minute one.

The drying apparatus, placed between the external air and the interior of the reservoir, consists of a tubulated bottle (with two openings) containing chloride of calcium, and connected with the reservoir by an India-rubber tube; by which arrangement the air is deprived of its moisture.

To ascertain the temperature of the column of the liquid two thermometers are attached, one at the top and the other near the bottom.

The whole apparatus is enclosed in an outer glazed case of twelve inches square, which serves (as mentioned before) as well for protection as for equalizing the temperature, which is ascertained with sufficient accuracy by taking the mean of the two thermometers.

A large correction is required in this barometer for the expansion and contraction by the changes of temperature. To determine the amount of this, the specific gravity of a quantity of the acid with which the barometer had been filled was taken at different temperatures. This process was performed with a very sensitive balance, by Dr. Easter, in the laboratory of the Institution.

STATEMENT IN RELATION TO THE HISTORY OF THE ELECTRO-MAGNETIC TELEGRAPH.*

(From the Smithsonian Annual Report for 1857, pp. 99–106.)

A series of controversies and law suits having arisen between rival claimants for telegraphic patents, I was repeatedly appealed to to act as *expert* and witness in such cases. This I uniformly declined to do, not wishing to be in any manner involved in these litigations; but I was finally compelled under legal process to return to Boston from Maine—whither I had gone on a visit, and to give evidence on the subject. My testimony was given with the statement that I was not a willing witness, and that I labored under the disadvantage of not having access to my notes and papers, which were in Washington.

In the beginning of my deposition I was requested to give a sketch of the history of electro-magnetism having a bearing on the telegraph, and the account I then gave from memory I have since critically examined, and find it fully corroborated by reference to the original authorities. My sketch, which was the substance of what I had been in the habit of giving in my lectures, was necessarily very concise, and almost exclusively confined to one class of facts, namely, those having a direct bearing on Mr. Morse's invention. In order therefore to set forth more clearly in what my own improvements consisted, it may be proper to give a few additional particulars respecting some points in the progress of discovery, illustrated by wood cuts.

There are several forms of the electrical telegraph; first, that in which frictional electricity has been proposed to produce sparks, and motion of pith balls at a distance.

Second, that in which galvanism has been employed to produce signals by means of bubbles of gas from the decomposition of water; or by other chemical re-action.

*[Presented to the Board of Regents of the Smithsonian Institution, on their investigation (by a special committee) of certain publications touching the origin of the electro-magnetic telegraph.]

Third, that in which electro-magnetism is the motive power to produce motion at a distance: and again, of the latter there are two kinds of telegraphs, those in which the intelligence is indicated by the motion of a magnetic needle and those in which sounds and permanent signs are made by the attraction of an electro-magnet. The latter is the class to which Mr. Morse's invention belongs. The following is a brief exposition of the several steps which led to this form of the telegraph :

The first essential fact (as I stated in my testimony) that rendered the electro-magnetic telegraph possible was discovered by Oersted, in the winter of 1819–20. It is illustrated by figure 1, in which the magnetic needle is deflected by the

FIG. 1.

action of a current of galvanism transmitted through the wire *A B*. (See *Annals of Philosophy*, Oct., 1820, vol. XVI, page 274.)

The second fact of importance, discovered in 1820 by Arago and Davy, is illustrated in figure 2. It consists in

FIG. 2.

this, that while a current of galvanism is passing through a copper wire *A B*, it is *quasi* magnetic, that is, it attracts iron filings in a cylindrical sheath around it, and not those of copper or brass, developing magnetism in soft iron. (See *Annales de Chimie et de Physique*, 1820, vol. XV, page 94.)

The next important discovery, also made in 1820, by Ampère, was that two wires through which galvanic currents are passing in the same direction attract—and in the opposite direction repel each other. On this fact Ampère founded

his celebrated theory that magnetism consists merely in the attraction of electrical currents revolving at right angles to the line joining the two poles of the magnet. The magnetization of a bar of steel or iron, according to this theory, consists in establishing within the metal by induction—a series of electrical currents, all revolving in the same direction at right angles to the axis or length of the bar.

It was this theory which led Arago, as he states, to adopt the method of magnetizing sewing needles and pieces of steel wire shown in figure 3. This method consists in trans-

FIG. 3.

mitting a current of electricity through a helix surrounding the needle or wire to be magnetized. For the purpose of insulation the needle was inclosed in a glass tube, and the several turns of the helix were at a distance from each other to insure the passage of electricity through the whole length of the wire, or in other words, to prevent it from seeking a shorter passage by cutting across from one spire to another. The helix employed by Arago obviously approximates the arrangement required by the theory of Ampère in order to develop by induction the magnetism of the iron. By an attentive perusal of the original account of the experiments of Arago (given in the *Annales de Chimie et Physique*, 1820, vol. xv, pages 93–95) it will be seen that properly speaking he made no electro-magnet, as has been often stated. His experiments were confined to the magnetizing of iron filings, sewing needles, and pieces of steel wire of the diameter of a millimetre, or of about the thickness of a small knitting needle.

Mr. Sturgeon, in 1825, made an important step in advance of the experiments of Arago, and produced what is properly known as the electro-magnet. He bent a piece of iron wire into the form of a horseshoe, covered it with varnish to insulate it, and surrounded it with a helix, of which the spires were at a distance. When a current of galvanism was

passed through the helix from a small battery of a single cup the iron wire became magnetic, and continued so during the passage of the current. When the current was interrupted the magnetism disappeared, and thus was produced the first temporary soft iron magnet.


FIG. 4.

The electro-magnet of Sturgeon is shown in figure 4, which is a copy from the drawing in the *Transactions of the Society for the Encouragement of Arts*, &c., 1825, vol. XLIII, pp. 38–52. By comparing figures 3 and 4, it will be seen that the helix employed by Sturgeon was of the same kind as that used by Arago; instead of a straight steel wire inclosed in a tube of glass however, Sturgeon employed a bent wire of soft iron. The difference in the arrangement at first sight might appear to be small, but the difference in the results produced was important, since the temporary magnetism developed in the arrangement of Sturgeon was sufficient to support a weight of several pounds; and an instrument was thus produced of value in future research.

The next improvement was made by myself. After reading an account of the galvanometer of Schweigger, the idea occurred to me that a much nearer approximation to the requirements of the theory of Ampère could be attained by insulating the conducting wire itself, instead of the rod to be magnetized, and by covering the whole surface of the iron with a series of coils in close contact. This was effected by insulating a long wire with silk thread, and winding this around the rod of iron in close coils from one end to the other. The same principle was extended by employing a still longer insulated wire, and winding several strata of this over the first, care being taken to insure the insulation between each stratum by a covering of silk ribbon. By this arrangement the rod was surrounded by a compound helix formed of a long wire of many coils, instead of a single helix of a few coils. (Fig. 5.)


FIG. 5.

In the arrangement of Arago and Sturgeon the several turns of wire were not precisely at right angles to the axis of the rod, as they should be—to produce the effect required by the theory, but slightly oblique, and therefore each tended to develop a separate magnetism not coincident with the axis of the bar. But in winding the wire over itself, the obliquity of the several turns compensated each other, and the resultant action was at right angles to the bar. The arrangement then introduced by myself was superior to those of Arago and Sturgeon, first in the greater multiplicity of turns of wire, and second in the better application of these turns to the development of magnetism. The power of the instrument, with the same amount of galvanic force, was by this arrangement several times increased.

The maximum effect however with this arrangement and a single battery was not yet obtained. After a certain length of wire had been coiled upon the iron, the power diminished with a further increase of the number of turns. This was due to the increased resistance which the longer wire offered to the conduction of electricity. Two methods of improvement therefore suggested themselves. The first consisted—not in increasing the length of the coil, but in using a number of separate coils on the same piece of iron. By this arrangement the resistance to the conduction of the electricity was diminished, and a greater quantity made to circulate around the iron from the same battery. The second method of producing a similar result consisted in increasing the number of elements of the battery, or in other words the projectile force of the electricity, which enabled it to pass through an increased number of turns of wire, and thus by increasing the length of the wire, to develop the maximum power of the iron.

FIG. 6.

To test these principles on a larger scale, the experimental magnet was constructed, which is shown in figure 6. In this a number of compound helices was placed on the same bar, their ends left projecting, and so numbered that

they could be all united into one long helix, or variously combined in sets of lesser length.

From a series of experiments with this and other magnets it was proved that in order to produce the greatest amount of magnetism from a battery of a single cup, a number of helices is required; but when a compound battery is used, then one long wire must be employed, making many turns around the iron, the length of wire and consequently the number of turns being commensurate with the projectile power of the battery.

In describing the results of my experiments, the terms "intensity" and "quantity" magnets were introduced to avoid circumlocution, and were intended to be used merely in a technical sense. By the *intensity* magnet I designated a piece of soft iron, so surrounded with wire that its magnetic power could be called into operation by an *intensity* battery, and by a *quantity* magnet, a piece of iron so surrounded by a number of separate coils, that its magnetism could be fully developed by a *quantity* battery.

I was the first to point out this connection of the two kinds of the battery with the two forms of the magnet, in my paper in Silliman's Journal, January, 1831, and clearly to state that when magnetism was to be developed by means of a compound battery, one long coil must be employed, and when the maximum effect was to be produced by a single battery, a number of single strands should be used.*

These steps in the advance of electro-magnetism, though small, were such as to interest and surprise the scientific world. With the same battery used by Mr. Sturgeon, at least a hundred times more magnetism was produced than could have been obtained by his experiment. The developments were considered at the time of much importance in a scientific point of view, and they subsequently furnished the means by which magneto-electricity, the phenomena of diamagnetism, and the magnetic effects on polarized light were discovered. They gave rise to the various forms of electro-

*[Silliman's American Journal of Science, Jan., 1831, vol. XIX, pp. 403, 404. See *ante*, vol. I, p. 42.]

magnetic machines which have since exercised the ingenuity of inventors in every part of the world, and were of immediate applicability in the introduction of the magnet to telegraphic purposes. Neither the electro-magnet of Sturgeon nor any electro-magnet ever made previous to my investigations was applicable to transmitting power to a distance.

The principles I have developed were properly appreciated by the scientific mind of Dr. Gale, and applied by him to operate Mr. Morse's machine at a distance.†

Previous to my investigations the means of developing magnetism in soft iron were imperfectly understood. The electro-magnet made by Sturgeon, and copied by Dana, of New York, was an imperfect quantity magnet, the feeble power of which was developed by a single battery. It was entirely inapplicable to a long circuit with an intensity battery, and no person possessing the requisite scientific knowledge, would have attempted to use it in that connection after reading my paper.

In sending a message to a distance, two circuits are employed, the first a long circuit through which the electricity is sent to the distant station to bring into action the second—a short one, in which is the local battery and magnet for working the machine. In order to give projectile force sufficient to send the power to a distance, it is necessary to use an intensity battery in the long circuit; and in connection with this at the distant station a magnet surrounded with many turns of one long wire must be employed to receive and multiply the effect of the current enfeebled by its transmission through the long conductor. In the local or short circuit either an intensity or quantity magnet may be employed. If the first be used, then with it a compound battery will be required; and therefore on account of the increased resistance due to the greater quantity of acid, a less amount of work will be performed by a given amount of material; and consequently though this arrangement is practicable it is by no means economical. In my original paper I state that the advantages of a greater conducting power, from using sev-

† [See Appendix A, at the end of this paper.]

eral wires in the quantity magnet may in a less degree be obtained by substituting for them one large wire; but in this case, on account of the greater obliquity of the spires and other causes, the magnetic effect would be less. In accordance with these principles, the receiving magnet, or that which is introduced into the long circuit, consists of a horseshoe magnet surrounded with many hundred turns of a single long wire, and is operated with a battery of from 12 to 24 elements or more, while in the local circuit it is customary to employ a battery of one or two elements with a much thicker wire and fewer turns.

It will I think be evident to the impartial reader that these were improvements in the electro-magnet which first rendered it adequate to the transmission of mechanical power to a distance; and had I omitted all allusion to the telegraph in my paper, the conscientious historian of science would have awarded me some credit, however small might have been the advance that I had made. Arago, and Sturgeon, in the accounts of their experiments, make no mention of the telegraph, and yet their names always have been and will be associated with the invention. I briefly called attention however to the fact of the applicability of my experiments to the construction of the telegraph; but not being familiar with the history of the attempts made in regard to this invention, I called it "Barlow's project," while I ought to have stated that Mr. Barlow's investigation merely tended to disprove the possibility of a telegraph.

I did not refer exclusively to the needle telegraph when I stated in my paper that "the *magnetic* action of a current from a trough is at least not sensibly diminished by passing through a long wire." This is evident from the fact that the immediate experiment from which this deduction was made, was by means of an electro-magnet and not by means of a needle galvanometer.

At the conclusion of the series of experiments which I described in Silliman's Journal, there were two applications of the electro-magnet in my mind: one, the production of a machine to be moved by electro-magnetism, and the other,

the transmission of or calling into action power at a distance. The first was carried into execution in the construction of the machine described in Silliman's Journal in 1831;* and for the purpose of experimenting in regard to the second, I arranged around one of the upper rooms in the Albany Academy a wire of more than a mile in length, through which I was enabled to make signals by sounding a bell. (Fig. 7.) The mechanical arrangement for effecting this object was simply a steel bar, permanently magnetized, of about ten inches in length, supported on a pivot, and placed with its north end between the two arms of a horse-shoe magnet. When the latter was excited by the current, the end of the bar thus placed was attracted by one arm of the horse-shoe, and repelled by the other, and was thus caused to move in a horizontal plane and its further extremity to strike a bell suitably adjusted.

FIG. 7.

This arrangement is that which is alluded to in Professor Hall's letter† as having been exhibited to him in 1832. It was not however at that time connected with the long wire above-mentioned, but with a shorter one put up around the room for exhibition.

At the time of giving my testimony I was uncertain as to when I had first exhibited this contrivance, but have since definitely settled the fact by the testimony of Hall and others that it was before I left Albany, and abundant evidence can be brought to show that previous to my going to Princeton in November, 1832, my mind was much occupied with the subject of the telegraph, and that I introduced it in my course of instruction to the senior class in the Academy. I

*[Silliman's American Journal of Science, July, 1831, vol. XX, pp. 340–343. See *ante*, vol. I, p. 54.]

†[See Appendix B, at the end of this paper; and also Proceedings of the Albany Institute, January 13, 1858; vol. IV, pp. 244, 245.]

should state however that the arrangement I have described was merely a temporary one, and that I had no idea at the time of abandoning my researches for the practical application of the telegraph. Indeed, my experiments on the transmission of power to a distance were suspended by the investigation of the remarkable phenomena (which I had discovered in the course of these experiments) of the induction of a current in a long wire on itself, and of which I made the first mention in a paper in Silliman's Journal in 1832.*

I also devised a method of breaking a circuit and thereby causing a large weight to fall. It was intended to illustrate the practicability of calling into action at a distance a great power capable of producing mechanical effects; but as a description of this was not printed, I do not place it in the same category with the experiments of which I published an account, or the facts which could be immediately deduced from my papers in Silliman's Journal.

From a careful investigation of the history of electro-magnetism in its connection with the telegraph, the following facts may be established:

1. Previous to my investigations the means of developing magnetism in soft iron were imperfectly understood, and the electro-magnet which then existed was inapplicable to the transmission of power to a distance.

2. I was the first to prove by actual experiment that in order to develop magnetic power at a distance a galvanic battery of "intensity" must be employed to project the current through the long conductor, and that a magnet surrounded by many turns of one long wire must be used to receive this current.

3. I was the first to actually magnetize a piece of iron at a distance, and to call attention to the fact of the applicability of my experiments to the telegraph.

4. I was the first to actually sound a bell at a distance by means of the electro-magnet.

* [Silliman's American Journal of Science, July, 1832, vol. XXII, p. 408. See *ante*, vol. I, p. 79.]

5. The principles I had developed were applied by Dr. Gale to render Morse's machine effective at a distance.

The results here given were among my earliest experiments: in a scientific point of view I considered them of much less importance than what I subsequently accomplished; and had I not been called upon to give my testimony in regard to them, I would have suffered them to remain (without calling public attention to them) a part of the history of science to be judged of by scientific men who are the best qualified to pronounce upon their merits.

APPENDIX A.—*Letter from Dr. Gale.*

WASHINGTON, D. C., *April* 7, 1856.

SIR: In reply to your note of the 3d instant, respecting the Morse telegraph, asking me to state definitely the condition of the invention when I first saw the apparatus in the winter of 1836, I answer: This apparatus was Morse's original instrument, usually known as the type apparatus, in which the types, set up in a composing stick, were run through a circuit breaker, and in which the battery was the cylinder battery, with a single pair of plates. This arrangement also had another peculiarity, namely, it was the electro-magnet used by Sturgeon, and shown in drawings of the older works on that subject, having only a few turns of wire in the coil which surrounded the poles or arms of the magnet. The sparseness of the wires in the magnet coils and the use of the single cup battery were to me, on the first look at the instrument, obvious marks of defect, and I accordingly suggested to the professor, without giving my reasons for so doing, that a battery of many pairs should be substituted for that of a single pair, and that the coil on each arm of the magnet should be increased to many hundred turns each; which experiment, if I remember aright, was made on the same day with a battery and wire on hand, (furnished I believe by myself,) and it was found that while the original arrangement would only send the electric current through a few feet of wire, say 15 to 40, the modified arrangement would send it through as many hundred. Although I gave no reason at the time to Professor Morse for the suggestions I had proposed in modifying the arrangement of the machine, I did so afterwards, and referred in my explanations to the paper of Professor Henry, in the 19th volume of the American Journal of Science, page 400 and onward. It was to these suggestions of mine that Professor Morse alludes in his testimony before the Circuit Court for the eastern district of Pennsylvania, in the trial of B. B. French and others *vs.* Rogers and others. See printed copy of complainant's evidence, page 168, beginning with the words, "Early in 1836 I procured 40 feet of wire," &c., and page 169, where Professor Morse alludes to myself and compensation for services rendered to him, &c.

At the time I gave the suggestions above named, Professor Morse was

not familiar with the then existing state of the science of electro-magnetism. Had he been so, or had he read and appreciated the paper of Henry, the suggestions made by me would naturally have occurred to his mind as they did to my own. But the principal part of Morse's great invention lay in the mechanical adaptation of a power to produce motion, and to increase or relax at will. It was only necessary for him to know that such a power existed for him to adapt mechanism to direct and control it.

My suggestions were made to Professor Morse from inferences drawn by reading Professor Henry's paper above alluded to. Professor Morse professed great surprise at the contents of the paper when I showed it to him, but especially at the remarks on Dr. Barlow's results respecting telegraphing, which were new to him; and he stated at the time that he was not aware that any one had even conceived the idea of using the magnet for such purposes.

With sentiments of esteem, I remain, yours truly,

L. D. GALE.

Prof. JOSEPH HENRY.

APPENDIX B.—*Letter from Prof. Hall.*

ALBANY, N. Y., *January* 19, 1856.

DEAR SIR: While a student of the Rensselaer School, in Troy, New York, in August, 1882, I visited Albany with a friend, having a letter of introduction to you from Professor Eaton. Our principal object was to see your electro-magnetic apparatus, of which we had heard much, and at the same time the library and collections of the Albany Institute.

You showed us your laboratory in a lower story or basement of the building, and in a larger room in an upper story some electric and galvanic apparatus, with various philosophical instruments. In this room, and extending around the same, was a circuit of wire stretched along the wall, and at one termination of this, in the recess of a window, a bell was fixed, while the other extremity was connected with a galvanic apparatus.

You showed us the manner in which the bell could be made to ring by a current of electricity, transmitted through this wire, and you remarked that this method might be adopted for giving signals, by the ringing of a bell at the distance of many miles from the point of its connection with the galvanic apparatus.

All the circumstances attending this visit to Albany are fresh in my recollection, and during the past years, while so much has been said respecting the invention of electric telegraphs, I have often had occasion to mention the exhibition of your electric telegraph in the Albany Academy, in 1832.

If at any time or under any circumstances this statement can be of service to you in substantiating your claim to such a discovery at the period named, you are at liberty to use it in any manner you please, and I shall be ready at all times to repeat and sustain what I have here stated, with many other attendant circumstances, should they prove of any importance.

I remain, very sincerely and respectfully, yours,

JAMES HALL.

Professor JOSEPH HENRY.

ON THE APPLICATION OF THE TELEGRAPH TO THE PREMONITION OF WEATHER CHANGES.

(Proceedings American Academy of Arts and Sciences, vol. IV, pp. 271–275.)

August 9, 1859.

Professor Henry made a verbal communication relative to the application of the telegraph to the prediction of changes of the weather, particularly in the city of Boston and its vicinity.

It has been fully established by the observations which have been made under the direction of the Smithsonian Institution, and from other sources of information, that the principal disturbances of the atmosphere are not of a local character, but commence in certain regions, and are propagated in definite directions over the whole surface of the United States east of the Rocky Mountains.

From a careful study of all the phenomena of the winds of the temperate zones it is inferred that over the whole surface of the United States and Canada there are two great currents of air continually flowing eastward. These currents consist of an upper and a lower, the former returning the air to the south which was carried by the latter towards the north. The lower current, which is continually flowing over the surface of the United States, is about two miles in depth, and moves from the southwest to northeast. The upper or return current, which is probably of nearly equal magnitude, flows from northwest to southeast, or nearly at right angles to the other, and the resultant of the two is a current almost directly from the west. The reaction of these two currents appears to be the principal cause of the sudden changes of weather in our latitude. They give definite direction to our storms, accordingly as the latter are more influenced by the motion of the one or the other of these great aerial streams. The principal American storms may from our present knowledge, be divided into two classes, namely those which have their origin in the Caribbean Sea and

those which enter our territory from the north at the eastern base of the Rocky Mountains. Those of the first class, which have been studied with much success by the lamented Redfield and others, follow the general direction of the Gulf Stream, and overlapping the eastern portion of the United States, give rise to those violent commotions of the atmosphere which are in many instances so destructive to life and property along our eastern coast. These storms from the south are frequently two or three days in traversing the distance from Key West to Cape Race, and their approach and progress might generally be announced by telegraph in time to guard against their disastrous effects. Though the general direction of these storms appears to be made out with considerable certainty, much remains to be done in settling the theory of their character and formation.

The materials which have been collected at the Smithsonian Institution during the last seven years relative to the other class of storms have enabled us to establish general facts of much value, not only in a scientific point of view, but also in their application to the prediction of the weather. [This statement was verified by a series of maps, exhibited to the Academy by Professor Henry, on which were indicated the beginning and progress of some remarkable changes of weather.] From these maps it appears that the great disturbances of the atmosphere which spread over the surface of the United States enter our territory from the possessions of the Northwest or Hudson's Bay Company, about the sources of the Saskatchewan, at the base of the Rocky Mountains, and are thence propagated south and east, until in many instances they spread over the whole of the United States and probably a large portion of the British possessions.

For example, the great depression of temperature which occurred in January of the present year, and which will be remembered by every one as the most marked cold period of the season, entered the territory of the United States at the point before mentioned on the 5th of January, and on the 6th reached Utah, on the 7th Santa Fé, and on the 8th the

Gulf of Mexico, and passing onward it was felt in Guatemala on the 10th. While it was advancing southward it was spreading over the continent to the east; on the 7th it reached the Red River settlement and all places under the same meridian, down to the Gulf of Mexico. It reached the meridian of Chicago on the 8th, the western part of the State of New York on the 9th, New England on the 10th, and Cape Race on the 13th. It moved with about equal velocity over the Southern States and was observed at Bermuda on the 12th.

The remarkable frost of last June, so far as it has been traced, had the same origin and followed the same eastward course. The fact was also illustrated, (by the maps before mentioned,) that the warm periods which have occurred in past years have followed the same law of progression, and consequently their approach could have been announced to the inhabitants of the Eastern States several days in advance had a proper system of telegraphic despatches been established.

The value of the telegraph in regard to meteorology has been fully proved by the experience of the Smithsonian Institution. The Morse line of telegraph has kindly furnished the Institution during the last twelve months, free of cost, with a series of daily records of the weather from the principal stations over the whole country east of the Mississippi river and south of New York. In order to exhibit at one view the state of the weather over the portion of the United States just mentioned a large map is pasted on a wooden surface, into which, at each station of observation, a pin is inserted, to which a card can be temporarily attached. The observations are made at about seven o'clock in the morning, and as soon as the results are received at the Institution, an assistant attaches a card to each place from which intelligence has been obtained, indicating the kind of weather at the time; rain being indicated by a black card, cloudiness by a brown one, snow by a blue one, and clear sky by a white card.

This meteorological map is an object of great interest to

the many persons from a distance who visit the Institution daily; all appear to be specially interested in knowing the condition of weather to which their friends at home are subjected at the time. But the value of the map is not confined to the gratification of this desire. It enables us to study the progress of storms, and to predict what changes in the weather may be expected at the east, from the indications furnished by places farther west. For example, if a black card is seen in the morning on the station at Cincinnati, indicating rain at that city, a rain storm may confidently be expected at Washington at about seven o'clock in the evening. Indeed, so uniformly has this prediction been verified, that last winter the advertising in the afternoon papers of the lectures to be delivered at the Institution that evening was governed by the condition of the weather in the morning at Cincinnati; a rainy morning at the latter inducing a postponement of the lecture.

It must be evident, from the facts given, that if a system of telegraphing over the whole country east of the Rocky Mountains were established, information could be given to the Middle and Eastern States of the approach of disturbances of the atmosphere,—of much value to the agriculturist, the ship-owner, and to all others who transact business affected by changes of weather, as well as of importance to the invalid and the traveller. Indeed, with a proper combination of the lines now in operation, daily intelligence might be obtained in the city of Boston which would be of the highest interest to its inhabitants. [Professor Henry mentioned Boston in particular, because this city is so situated that the storms, both of the southern and western class, reach it after they have been felt in New York and in other places which are not so far east and north.] It is necessary to remark that the same use of the telegraph is in a measure inapplicable to the inhabitants of Western Europe, since they live on the eastern side of an ocean, and cannot be apprised of the approach of storms from the west. For the same reason the general laws of storms are more conveniently

studied by the meteorologists of this country than by those of Great Britain and France.

It should be distinctly understood that the remarks which have been made in this communication relate to the more violent changes of the weather which occur in autumn, winter, and spring. The thunder showers which occur almost daily during the warm weather in summer have somewhat of a local character, and commence at the same time and frequently at the same hour for several days in succession, at the same and different places; but wherever they commence they move eastward over the country until they are exhausted.

Professor Henry also spoke of the facts collected in regard to the nature of American storms, and their connection with the two great aerial currents continually flowing over the temperate zone. He considered that the great changes of the weather are principally due to the gradual production of an unstable equilibrium in the two currents by the accumulation of heat and moisture in the lower.

He spoke in high terms of the importance of the labors of Mr. Espy in developing the theory of the upper motion of air and the evolution of latent heat in the production of storms.

In reply to a question as to the possibility of crossing the Atlantic in a balloon, the Professor stated that he had little doubt, if the balloon could be made to retain the gas and to ascend into the upper current, it would be wafted across the ocean in the course of three or four days. If it descended into the lower current it would be carried to the north of east, and if it continued in the upper current it would reach Europe south of the same point. The course could be changed, within certain limits, by ascending and descending from one current to the other. The late balloon voyage from St. Louis to Jefferson county, New York, was of interest in confirming the theoretical direction of the great lower current of this latitude.

ON THE UTILIZATION OF ATMOSPHERIC CURRENTS IN AERONAUTICS.*

(From the Smithsonian Annual Report for 1860, pp. 118, 119.)

March 11, 1861.

DEAR SIR: In reply to your letter of February 25, 1861, requesting that I would give you my views in regard to the currents of the atmosphere and the possibility of an application of a knowledge of them to aerial navigation, I present you with the following statement to be used as you may think fit.

I have never had faith in any of the plans proposed for navigating the atmosphere by artificial propulsion, or for steering a balloon in a direction different from that of the current in which the vehicle is floating.

The resistance to a current of air offered by several thousand feet of surface is far too great to be overcome by any motive power at present known which can be applied by machinery of sufficient lightness.

The only method of aerial navigation which in the present state of knowledge appears to afford any possibility of practical application is that of sailing with the currents of the atmosphere. The question therefore occurs as to whether the aerial currents over the earth are of such a character that they can be rendered subservient to aerial locomotion.

In answering this question I think I hazard little in asserting that the great currents of the atmosphere have been sufficiently studied to enable us to say with certainty that they follow definite courses, and that they may be rendered subservient to aerial navigation provided the balloon itself can be so improved as to render it a safe means of locomotion.

It has been established by observations now extending over two hundred years, that at the surface of the earth

*[A letter addressed to Mr. T. S. C. Lowe, the Aeronaut, dated Washington, D. C., March 11, 1861.]

within the tropics, there is a belt along which the wind constantly blows from an easterly direction; and from the combined meteorological observations made in different parts of the world within the last few years, that north of this belt, between the latitudes of 30° and 60° around the whole earth, the resultant wind is from a westerly direction.

The primary motive power which gives rise to these currents is the constant heating of the air in the equatorial, and the cooling of it in and toward the polar regions; the eastern and western deflections of these currents being due to the rotation of the earth on its axis.

The easterly currents in the equatorial regions are always at the surface and have long been known as the trade winds, while the currents from the west are constantly flowing in the upper portion of the atmosphere, and only reach the surface of the earth at intervals,—generally after the occurrence of a storm.

Although the wind (at the surface) over the United States and around the whole earth between the same parallels, appears to be exceedingly fitful, yet when the average movement is accurately recorded for a number of years, it is found that there remains a large resultant of a westerly current. This is well established by the fact that on an average of many years packet ships sailing between New York and Great Britain occupy nearly double the time in returning that they do in going.

It has been fully established by continuous observations for ten years collected at this Institution from every part of the United States, that as a general rule all the meteorological phenomena advance from west to east, and that the higher clouds always move eastwardly. We are therefore from abundant observations as well as from theoretical considerations, enabled to state with confidence that on a given day, whatever may be the direction of the wind at the surface of the earth, a balloon elevated sufficiently high would be carried eastwardly by the prevailing current in the upper or rather middle region of the atmosphere.

I do not hesitate therefore to say that provided a bal-

loon can be constructed of sufficient size and of sufficient impermeability to gas to maintain a high elevation for a sufficient length of time, it would be wafted across the Atlantic. I would not however advise that the experiment of this character be made across the ocean, but that the feasibility of the project should be thoroughly tested and experience accumulated by voyages over the interior of our continent. It is true that more eclat might be given to the enterprise and more interest excited in the public mind generally by the immediate attempt of a passage to Europe; but I do not think the sober sense of the more intelligent part of the community would be in favor of this plan; on the contrary, it would be considered a premature and fool-hardy risk of life.

It is not in human sagacity to foresee prior to experience what simple occurrence, or what neglect in an arrangement, may interfere with the result of an experiment; and therefore I think it will be impossible for you to secure the full confidence of those who are best able to render you assistance, except by a practical demonstration in the form of successful voyages from some of the interior cities of the continent to the seaboard.

SYSTEMATIC METEOROLOGY IN THE UNITED STATES.

(From the Smithsonian Annual Report for 1865, pp. 50–59.)

It has been aptly said that man is a meteorologist by nature. He is placed in such a state of dependence upon the atmospheric elements, that to watch their vicissitudes and to endeavor to anticipate their changes become objects of paramount importance. Indeed the interest in this subject is so absolute that the common salutation among civilized nations is a meteorological wish, and the first introduction to conversation among stangers is a meteorological remark. Yet there is no circumstance which is remembered with so little exactness as the previous condition of the weather, even from week to week. In order that its fluctuations may be preserved as facts of experience, it is necessary that they should be continuously and accurately registered. Again, there is perhaps no branch of science relative to which so many observations have been made and so many records accumulated, and yet from which so few general principles have been deduced. This has arisen, first, from the real complexity of the phenomena, or in other words from the number of separate causes influencing the production of the ordinary results; second, from the improper methods which have been pursued in the investigation of the subject, and the amount of labor required in the reduction and discussion of the observations. Although the primary causes of the change of the weather are on the one hand, the alternating inclination of the surface of the earth to the rays of the sun, by which its different parts are unequally heated in summer and in winter, and on the other, the moisture which is elevated from the ocean in the warmer and precipitated upon the colder portions of the globe; yet the effects of these are so modified by the revolution of the earth on its axis, the condition and character of the different portions of its surface, and the topography of each country, that to strictly calculate the perturbations or predict the results of the simple laws of atmospheric equilibrium with that precision which

is attainable in astronomy, will probably ever transcend the sagacity of the wisest, even when assisted by the highest mathematical analysis. But although such precision cannot be looked for, approximations may still be obtained of great importance in their practical bearing on the every-day business of life.

The greater part of all the observations which have been recorded until within a few years past has been without system or co-ordination. It is true that the peculiar climate of a given place may be determined by a long series of isolated observations, but such observations, however long continued, or industriously and accurately made, can give no adequate idea of the climate of a wide region, of the progress of atmospheric changes, nor can they furnish an approximation to the general laws of the recurrence of phenomena. For this purpose a system of observation must be established over widely extended regions within which simultaneous records are made and periodically transmitted to a central position, where by proper reduction and discussion, such general conclusions may be reached as the materials are capable of yielding.

In discussing the records, the empirical method does not suffice. It is necessary that *a priori* assumptions should be provisionally adopted, not however at random, but chosen in strict accordance with well-established physical principles, and that these be finally adopted, rejected, or modified, as they are found to agree or disagree with the records. It is only by this method that the different causes which co-operate in the production of a series of complex phenomena can be discovered, as is illustrated in the history of astronomy, which previous to the investigations of Kepler consisted of an unintelligible mass of records of observations. But even with the application of the best possible process of discussion the labor necessary to be expended on such large masses of figures, in order to deduce simple results, is far beyond any individual effort, and can only be properly accomplished by governmental aid.

The importance of a combined system of meteorological

observations extending over a large area, and the peculiar advantages presented by our country for this object, were early appreciated, and such a system was commenced in 1819, under the direction of Dr. Lovell, Surgeon General of the Army. The stations embraced the principal military posts, from which reports were made at the end of each month as to the temperature, the pressure, and the moisture of the air, the amount of rain, the direction and force of the wind, the appearance of the sky, besides casual phenomena, such as the aurora, thunder-storms, shooting stars, &c. In 1825 a similar system, of more numerous stations in proportion to the area embraced, was established in the State of New York, the points of observation being the several academies under the direction of the board of regents of the University, an establishment having charge of the higher institutions of learning in that State.

In 1837 the Legislature of Pennsylvania made an appropriation of four thousand dollars for instruments, which were distributed to volunteer observers. This system was continued about ten years; that of New York has been kept up with more or less efficiency until the present time; while the army system was continued until the commencement of the war.

The lake system, established by the engineer department, under the superintendence of Captain (now General) Meade, consists of a line of stations, extending from the western part of Lake Superior to the eastern part of Lake Ontario, and has been efficiently continued for several years.

The Smithsonian meteorological system was commenced in 1849, and with occasional aid in defraying the expenses, has continued in operation until the present period. It was however much diminished in efficiency during the war, since from the southern States no records were received, and many of the observers at the north were called to abandon such pursuits for military service in the field. The efforts of the Institution in this line have been directed to supplementing and harmonizing all the other systems, preparing and distributing blank forms and instructions, calculating

and publishing extensive tables for the reduction of observations, introducing standard instruments, and collecting all public documents, printed matter, and manuscript records, bearing on the meteorology of the American continent, submitting these materials to scientific discussion, and publishing the results. In these labors the Institution has been in continued harmonious co-operation with all the other efforts made in this country to advance meteorology, except those formerly conducted by the Navy Department under Lieutenant Maury. These were confined exclusively to the sea, and had no reference to those made at the same time on land. Without desiring to disparage the labors of Lieutenant Maury, I may say that his results would have lost nothing of their value by the adoption of a less exclusive policy on his part. The meteorology of the sea and that of the land pertain to a connected series of phenomena which can be properly studied only by a combined system of observations relating to both. The method pursued by Lieutenant Maury consisted in dividing the surface of a map of the ocean into squares of ten degrees on a side, and in recording within each of these the direction of the winds obtained from the log-books of the vessels which had traversed the several regions. In this way he accumulated a large amount of data, which though published in connection with many crude hypotheses, are of great value in the study of the meteorology of the globe.

In 1853 a meteorological system was commenced in Canada, the senior grammar school in each county being provided with instruments; and the observations have been continued to the present time. In regard to this system, Mr. Hodgins of the educational department remarks: "We have never lost sight of the great practical importance to a new and partially settled country, of establishing early in its history, before its physical condition is materially changed, a complete and comprehensive system of meteorological observations, by which may be tested theories of science which are yet unsettled, and which may be solved, relating to natural phenomena which have long remained among the sealed mysteries of nature."

The observations thus far have been taken without remuneration, but the importance of the system has become so well recognized, that the Canadian government has decided to establish ten permanent stations, in addition to the observatories at Toronto and Kingston, distributed so as to afford the most complete information relative to the climatic features of the whole province. The points selected are Windsor, Goderich, Stratford, Simcoe, Barrie, Hamilton, Peterborough, Belleville, Pembroke, and Cornwall; that is, two stations on Lake Erie, one on Lake Huron, three on Lake Ontario, one on Lake Simcoe, one on the Ottawa river, one on the bay of Quinté, one on the St. Lawrence, near the eastern extremity of the province, and two in the interior of the country. The records made at the public schools of Canada have been furnished to the Smithsonian Institution, as well as to the committee on immigration of the New York House of Assembly, for the purpose of furnishing facts relative to the climate—of importance to settlers; and recently the department of royal engineers has applied for the returns, with a view to the consideration of their bearing on questions of defence. To secure a greater degree of responsibility, and to promote the efficiency of the system, the government has provided for the payment of fifty cents a day to the teachers of the grammar schools at the stations before enumerated, as remuneration for the service rendered.

Under the direction of the distinguished academician Kupfer, there is established over the vast Russian territory a network of thirty meteorological stations, where are noted the various changes of the atmosphere as to temperature, pressure, moisture, &c. The most northern of these stations is at Hammerfest, in 70° 41′ north latitude, 21° 26′ east longitude from Paris, and the most southern is at Tiflis, in 41° 42′ north latitude, and 42° 30′ east longitude.

A like system of simultaneous observations has been for several years in operation in Great Britain and Ireland, in connection with the Board of Trade, and under the direction of the late Admiral Fitzroy.

Other and similar systems of meteorology have been

established in France, Italy, and Holland. From these different organizations, as well as from insulated observatories, telegrams of the weather are sent every morning, at seven o'clock, from the principal cities of Europe to Paris, where under the superintendence of the celebrated Leverrier, they are discussed, and the results transmitted by mail to all parts of the world in the successive numbers of the daily International Bulletin. A similar publication is periodically made in Italy, under the direction of M. Matteucci, so well and favorably known by his discoveries in physics. The British Government has also established a system of observations for the sea, and furnished its navy with accurate instruments, carefully compared with the standards of the Kew observatory. It is estimated in a report to Parliament that through an annual appropriation of about fifty thousand dollars, statistics may be collected in fifteen years sufficient, with what has already been obtained, to determine the average movement of the winds on every part of the ocean.

From the great interest which has been awakened in regard to meteorology throughout the world, and the improved methods which have been adopted in its study, it can scarcely be doubted that in a few years the laws of the general movements of the atmosphere will be ascertained, and the causes of many phenomena of the weather, which have heretofore been regarded as little else than the capricious and abnormal impulses of nature, will become adequately known; although, from the number of these causes, and the complexity of the resultant effect, it may never be possible to deduce accurate predictions as to the time and particular mode of their occurrence.

Indeed, the results which have been already derived from the series of combined observations in this country, fully justify the wisdom and forethought of those who were instrumental in establishing them. Although their organization was imperfect, the observers in most cases untrained, and the instruments of an inferior character, yet they have furnished data which through the labors of Redfield, Espy, and

Hare, whose memories are preserved in the history of science, have led to the establishment of principles of high theoretical interest, as well as of great practical value. Among these I need here mention only the fact now fully proved that all the meterological phenomena of at least the middle and more northern portions of the temperate zone are transmitted from west to east. The passage of storms from one part of the country to the other was noticed by Dr. Franklin on the occasion of observing an eclipse of the moon. He showed that our south-west storms are felt successively later and later as the point of observation is farther to the north-east; that they arrive last at the extreme north-eastern portions of our continent. We now know however that the successive appearance of the storm at points farther along the coast is due to the easterly movement—sideways as it were, of an atmospheric disturbance, greatly elongated north and south, and reaching sometimes from Canada to the Gulf of Mexico. Hence to persons residing along the seaboard the phenomenon would appear to have a northwardly progression, on account of the north-easterly trend of the coast; yet the storm not unfrequently reaches simultaneously Bermuda and Nova Scotia.

Few persons can have failed to observe the continued motion of the higher clouds from the west, or to have recognized the just meteoroscopy of Shakspeare in a well-known passage:

> "The weary sun hath made a golden set,
> And by the bright track of his fiery car
> Gives token of a goodly day to-morrow."

The breaking forth of the sun just before his setting shows that the rear of the cloud which has obscured his beams has in its easterly course reached our horizon, and will soon give place to an unobscured sky.

It must be observed however that all the storms which visit our coast are not of this nature; those denominated cyclones, and which seldom extend far into the interior, are probably of a rotatory character. These usually commence in the Caribbean sea, move first toward the northwest, and

gradually curving round before they reach our latitude, take an easterly direction, as has been shown by Redfield and others.

The first practical application which was attempted of the principle we have mentioned was made by this Institution in 1856; the information conveyed by telegraphic despatches in regard to the weather was daily exhibited by means of differently colored tokens, on a map of the United States, so as to show at one view the meteorological condition of the atmosphere over the whole country. At the same time publication of telegraphic despatches was made in the newspapers. The system however was necessarily discontinued at the beginning of the war, and has not yet been resumed. Similar applications have since been made in other countries, particularly in England, under the late Amiral Fitzroy; in France, under Leverrier; and still later, in Italy. In the last-mentioned country tabular statements are to be published annually, comparing the predictions with the weather actually experienced.

The British Government has also recently introduced the system of telegraphic meteorological predictions into India. The cyclone of October, 1864, which did such damage to the shipping in Calcutta and destroyed the lives of sixty thousand persons, called special attention to the subject. The Asiatic Society of Bengal estimated the cost of such a system at 67,000 rupees (about $30,000), a sum which the government hesitated to appropriate, though it decided to furnish the necessary instruments and an allowance of fifty rupees a month to the assistant at the telegraph station at Saugor, on the seaboard to the southward of Calcutta, in the direction from which the most severe storms approach that port.

It must be evident from what we have said in regard to the movement of storms, that a system of telegraphic meteorological predictions would be at once more reliable and of more benefit to the eastern coast of the United States, than those made in England and France, on the western coast of Europe, could possibly be to those countries, since the dis-

turbances of the atmosphere which reach them advance from the ocean, while the majority of those of a similar nature which visit especially the middle and eastern portions of our coast, come overland from a westerly or south-westerly direction, and their approach may be telegraphed in some cases many hours before their actual arrival.

But the expense of the proper establishment of a system of this kind can only be defrayed by the general government or some organization in possession of more ample means than can be applied by the Smithsonian Institution to such a purpose. This will be evident from the fact which we have mentioned of the cost of the establishment of a similar system in India, and from a report of a committee of the two houses of Parliament appointed to consider certain questions relating to the meteorological department of the board of trade. From this it appears that the amount expended during the eleven years ending with 1865 was 45,000 pounds sterling, or an average of about $20,000 a year. The same committee recommend that meteorological observations at sea be continued under the direction of the hydrographic office of the admiralty, and an appropriation of £1,500 annually be made for instruments, and £1,700 for discussion and publication of results; making a total of £3,200. For weather statistics on land, the annual sum of £4,250, including instruments, discussion, and publications, is recommended, and for telegram storm warnings, £3,000; making a total annual expenditure of £7,450 for the land, and a grand annual total for land and sea of £10,450, or $52,250.

The present would appear to be a favorable time to urge upon Congress the importance of making provision for re-organizing all the meteorological observations of the United States under one combined plan, in which the records should be sent to a central depot for discussion and final publication. An appropriation of $50,000 annually for this purpose would tend not only to advance the material interests of the country but also to increase its scientific reputation. It would show that although the administration of our Government is the expression of the popular will, it is not

limited in its operation merely to objects of instant or immediate utility, but that with a wise prevision of the future it withholds its assistance from no enterprise, however remote the results, which has for its end to advance the well-being of humanity.

It is scarcely necessary at this day to dwell on the advantages which result from such systems of combined observations as those which the principal governments of Europe have established and are now constantly extending. I may however in passing, briefly allude to some facts which may not at once occur to the mind of the general reader. They enable the mariner to shorten the time and diminish the danger of the passage from one port to another by indicating to him the route along which prevail at a particular season of the year the most favorable winds for his purpose. They also furnish the means by which the sailor is taught the important lesson which has saved thousands of lives and millions of property, namely, that of finding the direction of the centre of the cyclone, and of determining the course in which he must steer in order to extricate himself from the destructive violence of this fearful scourge of the ocean. To the agriculturist they indicate the character of the climate of the country, and enable him with certainty to select the articles of culture best adapted to the temperature and moisture of the region, and which in the course of a number of years will insure him the most profitable returns for his labor. They furnish the statistics of the occurrence of sterile years and of devastating storms, which may serve as the basis on which to found insurance institutions for protection against the failure of crops, and thus give to the husbandman the same certainty in his pursuits as that possessed by the merchant or the ship-owner. They may also afford warning of the approach of severe frosts and violent storms, in time to guard at least in some degree against their injurious effects. To the physician a knowledge of such results as can be obtained from an extended system of observations is of great importance, not only in regard to the immediate practice of his art, but also to the improvement of his science.

The peculiar diseases of a region are principally dependent on its climate; an extreme variation of temperature in a large city is invariably attended with an increase of the number of deaths. The degree and variation of the moisture at different times and in different places have also a great influence on diseases, and the more the means of studying the connection of these elements and the corresponding condition of the human body are multiplied the more will the art and the science of medicine be improved. I may mention that scarcely a week passes at the Institution in which application is not made for meteorological information relative to different parts of this country, with the hope to improve the condition, if not restore the health, of some patient. The knowledge which at present exists however as to the connection of climate and disease, particularly in our own country, is—in comparison to what might be obtained—of little significance.

No other part of the world can at all compare with this country in the conditions most favorable to the advancement of meteorology, by means of a well-organized and properly sustained system of combined observations. Such a system extending from east to west more than two thousand miles would embrace in its investigation all the phenomena of the great upper current of the return trade wind, which continually flowing over us at a high elevation carries most of the disturbances of the atmosphere eastward. It would also include the effects produced by the polar and equatorial currents as they contend for the mastery along the broad valley which stretches without interruption from the arctic circle to the Gulf of Mexico, and would settle with precision the influence of the great fresh-water lakes in ameliorating the climate of the adjacent regions. But above all, in a popular view, it would furnish the means more effectually than any other system—of predicting the approach of storms and of giving the ships of our Atlantic coast due warning of the probability of danger.

REMARKS ON "VITALITY."*

(From the Smithsonian Annual Report for 1866, pp. 386–388.)

In the early study of mechanical and physiological phenomena, the energy which was exhibited by animals, or in other words, their power to perform what is technically called work, that is to overcome the inertia and change the form of matter, was referred to the vital force. A more critical study of these phenomena has however shown that this energy results from the mechanical power stored away in the food and material which the body consumes; that the body is a machine for applying and modifying power, precisely similar to those machines invented by man for a similar purpose. Indeed, it has been shown by accurate experiments that the amount of energy developed in animal exertion is just in proportion to the material consumed. To give a more definite idea of this, we may state the general fact that matter may be considered under two aspects, namely matter in a condition of power, and matter in a state of entire inertness. For example, the weight of a clock or the spring of a watch when wound up is in a state of power, and in its running down gives out, tick by tick, an amount of power precisely equal to the muscular energy expended in winding it up. When the weight or the spring has run down, it is then in a condition of inertness, and will continue in this state, incapable of producing motion, unless it be again put in a condition of power by the application of an extraneous force. Again, coal and other combustible bodies consist of matter in a condition of power, and in their running down into carbonic acid and water, during their combustion, evolve the energy exhibited in the operations of the steam engine. The combustible material may be considered the food of the steam engine, and experiments have been made to ascertain

*[Remarks on a communication "On Vitality," by the Rev. H. H. Higgins, in the Proceedings of the Literary and Philosophical Society of Liverpool, (England,) 1864. Re-printed in the Smithsonian Report for 1866, pp. 379–386.]

the relative economy in the expenditure of a definite amount of food in the natural machine and the artificial engine. The former has been found to waste less of the motive power than the latter.

In pursuing this train of investigation the question is asked, "Whence does the coal or food derive its power?" The answer is, that these substances are derived from the air by the decomposing agency of the impulses from the sun, and that when burned in the engine or consumed in the body they are again resolved into air, giving out in this resolution an amount of energy equivalent to that received from the sun during the process of their growth. All the materials of the crust of the earth, with the exception of coal and organic matter, are in a state of inertness, and like the burnt slag of the furnace, have expended their energy, and in this condition of inertness they would forever remain, were it not for extraneous influences, principally that from the sun.

From this point of view the phenomena we have been considering consist merely in the transfer of power from one body to another, and from a wide generalization from all the facts, the conclusion has been arrived at that energy is neither lost nor gained in the transfer; and pursuing the same train of reflection, we are finally led to the result that all power is derived from the primordial, unbalanced attraction and repulsion of the atoms of matter.

In the gradual development of the principles we have given there has been a tendency to extend the views we have presented too far, and to refer all the phenomena of life to the mechanical or chemical forces of nature. Although it has been, as we think, conclusively proved that from food, and food alone, come all the different kinds of physical force which are manifest in animal life, yet as the author of the preceding paper has shown, there is something else necessary to life, and this something, though it cannot properly be called a force, may be denominated the vital principle. Without the influence of this principle the undirected physical powers produce mechanical arrangements and assume a

state of permanent equilibrium by bringing matter into crystalline forms or intò a condition of simple aggregation, while under *its* mysterious influence the particles of matter are built up into an unstable condition in the form of organic molecules. While therefore we may refer the changes which are here produced, or in other words the work performed, to the expenditure of the physical powers of heat, chemical action, &c., we must admit the necessity of something beyond these which from the analogy with mental phenomena, we may denominate the directing principle. Although we cannot perhaps positively say in the present state of science that this directing principle will not manifest itself when all the necessary conditions are present, yet in the ordinary phenomena of life which are everywhere exhibited around us, organization is derived from vitality, and not vitality from organization. That the vital or directing principle is not a physical power which performs work, or that it cannot be classed with heat or chemical action, is evident from the fact that it may be indefinitely extended —from a single acorn a whole forest of oaks may result.

The principles of which we have here endeavored to give an exposition are strikingly illustrated in the transformation of the egg when subjected to a slightly elevated temperature. The egg of a bird for example consists, as we know, of a congeries of organized molecules or vesicles, enclosed in a calcareous shell, thickly punctured with minute holes, through which the oxygen of the air can enter, and vapors and gases escape. Let us observe the difference of changes which take place in two newly-laid eggs, one of which is not possessed with vitality, and the other is endowed with this mysterious principle. Both of these eggs are in a condition of power, the carbon, hydrogen, nitrogen, sulphur, &c., of which their organized molecules are composed, are in a state of unstable equilibrium and ready, when set in motion by a slight increase of temperature, to rush into the more stable compounds of carbonic acid, vapor of water, &c., by chemical attraction. While the eggs are in an unchanged condition they possess the same amount of what is called potential energy, which

in both cases will be expended in the transformation of the materials; but how different will be the effects produced. In the case of the egg deprived of vitality, all the organized molecules will be converted into gases and vapors, with the development of heat and an elastic energy, in some cases sufficient to burst the shell, the power originally stored away in the egg being thus dissipated in the production of chemical and mechanical changes. In the case of the egg possessed of vitality, a portion of the organized molecules will also run down into vapors and gases, which will gradually escape through the perforations of the shell, and will thus, as in the previous case, evolve an equivalent amount of power; but this, instead of being dissipated in mere mechanical or chemical effects, will be expended, under the directing principle of vitality, in elevating to a higher degree of organization the molecules of the remainder, and in transforming them into organs of sensation, perception, and locomotion; in short, in the production of a machine precisely similar to those constructed by the intellectual operations of man when guiding or directing the powers of nature. If we examine the transformation as it goes on from day to day, we shall see that it does not consist in a simple aggregation of particles in the production of the organs we have mentioned, but in preliminary arrangements, such as canals, and provisional parts, afterwards to be obliterated, and the adoption of means for a more remote end, the whole indicating an intention realized in the sentient, living, moving animal.

This vital principle, from strict analogy, cannot be considered as an essential property of matter, since it is only continued by transmission from one living being to another. It is true that it ceases to manifest itself when a slight derangement takes place in the organized material with which it is connected, and death ensues; but this is precisely analogous to the manifestation of the thinking, willing principle within us, the existence of which is revealed to us by our own consciousness as a primordial truth, beyond which nothing can be more certain.

SUGGESTIONS AS TO THE ESTABLISHMENT OF A PHYSICAL OBSERVATORY.*

(From the Smithsonian Annual Report for 1870, pp. 141-144.)

December 29, 1870.

MY DEAR SIR: Yours of the 28th of November was duly received, but I delayed answering it until the pressure of business which accumulated during my absence should have somewhat subsided, and also that I might receive the plans which you mention. I am now gratified in being able to inform you that my visit to Europe was both pleasant and profitable, and that I have returned much inproved in health, and with enlarged views as to the present state of science in the Old World.

While abroad I gave special attention to physical observatories, of which there are several in England and on the continent, although no one of them fully realizes my idea of what such an establishment ought to be.

A physical observatory is one the primary object of which is to investigate the physical phenomena of the earth and the heavenly bodies in contradistinction to an ordinary astronomical observatory, which is principally devoted to the observation and discussion of the motions of the planets, and the determination of the relative positions of the fixed stars. Of the latter kind but one or two are needed in any country, and as these require a numerous corps of observers and computors they can only be supported by appropriations annually from a national government. The United States Observatory at Washington is of this character, and including all expenses requires an annual appropriation of at least $50,000. The labors of such an observatory are indispensible to the advancement of the science of theoretical astronomy, and its application to geodesy and geography.

The establishment I would advise you to found is of the character of the one first mentioned, namely a physical observatory, the principal object of which would be, as I have

*[A letter addressed to Mr. Leander McCormick, dated Washington, December 29, 1870.]

indicated, to investigate the nature and changes of the constitution of the heavenly bodies; to study the various emanations from these in comparison with the results of experiments, and to record and investigate the different phenomena which are included under the general term of terrestrial physics.

A wide field has been opened for the study of the nature of the sun and other heavenly bodies by the application of the spectroscope, different modifications of the telescope, and other lately invented appliances. We now know that the sun is undergoing remarkable changes, the character of which can only be ascertained by the results of accurate observations compared with those of experimental investigation. The observer should divide his attention between the phenomena revealed by a critical and continued examination of the sun and the production of similar phenomena in the laboratory. In this way European investigators have arrived at most interesting results.

Again, we know that the emanations from the sun, and probably from the stars, differ essentially in character. There is first, the emanation known as light, which of itself consists of various rays (generally indicating the incandescence of substances,) that give the sensation of different colors, some of which though in their ordinary condition imperceptible to the eye, may be perceived by that organ after they have passed through certain liquids; next, the heat emanation, which is also of different kinds; then the chemical emanation, by which photographic impressions are produced; and lastly, the phosphorogenic emanation (abounding also in the electric discharge), that produces the temporary glow of the diamond and the luminosity of the compounds of lime, barium, and other substances with sulphur, when taken into the dark. To study these or other emanations as they may appear in the fixed stars, or are reflected from the moon and planets, or as they may be found in the aurora borealis, the zodiacal light, and in shooting-stars or larger meteors, requires peculiar instruments, and such as are not found, at

present, in ordinary astronomical observatories. For example, the celestial phenomena which address themselves to the sense of sight are studied by means of refracting telescopes, as are also those of the photographic ray, although this requires a peculiar form of lens, while the heat-ray of lower intensity and the phosphorogenic ray are not transmitted by glass; the former is readily converged to a focus by a lens of rock-salt, and the latter by one of quartz. They may all however as in the case of light, be concentrated into foci by metallic reflectors.

In regard to terrestrial physics, the phenomena are also various, and the forces by which they are produced are constantly changing both in intensity and in some cases in direction. We now know that the magnetism of the earth scarcely remains the same from one moment to another, and that these changes are connected with the appearance of the aurora borealis and electrical discharges in the atmosphere. They also in all probability may ultimately be referred to disturbances produced by external influences, such as those from the sun, moon, and planets. Furthermore, we may now consider the whole earth as an immense conductor charged with negative electricity, of which the intensity is in a continued state of change, and of the laws of which, as well as those of the changes of magnetism, a knowledge is highly desirable. For the proper study of these, continuous self-recording instruments are necessary.

There is also an important field of observation in regard to ordinary meteorology, such as the changes of the pressure of the atmosphere, and its connection with other phenomena; of the normal and abnormal winds; isolated currents of the atmosphere, and especially those of a vertical direction; the radiation of heat from clouds and different terrestrial surfaces; the variation of its intensity in ascending above and penetrating below the surface of the earth, &c. In short, the field is almost boundless, and every year reveals new facts in terrestrial and celestial physics, which never fail to furnish new points for investigation to those who are qualified by education and endowed by nature for their proper appreciation.

The conductor of an observatory such as I have mentioned to be successful must have peculiar characteristics. He must possess a minute knowledge of all the latest discoveries in physics, a keen eye to detect new appearances, imagination to suggest hypothetical causes, logical power to deduce consequences from these, to be tested by observation or experiment, and ingenuity to devise apparatus for verifying or disproving his deductions. When *such* a man is found he should be consecrated to science and fully furnished with all the implements necessary for the prosecution of his researches, those of physics as well as of astronomy, and himself and family placed beyond all anxiety as to the supply of their necessary wants. It may not be amiss to combine with his studies and duties, in the way of research, a small amount of lecturing,—just enough by sympathetic communication with admiring pupils to fan as it were his enthusiasm, and to impart a portion of it to others. He should also have at his command a skillful workman who under his direction could construct the temporary apparatus which are constantly required in original research. It is also important that he be associated with the faculty of a well-endowed college or university, to which he will become an important acquisition both in regard to the reputation which he will give to the institution and the effect he will have on the other members of the faculty in the way of stimulating them to higher efforts. In such an association he can call for the co-operation of the professors, and especially that of the physicist, the chemist, and the mathematician.

One of the most important points perhaps to which I should call your attention, is that of the building to be erected, since from the tendency to error in this line more injury has resulted to public institutions in this country than from any other cause. It should be recollected that "money is power;" that every dollar possesses a definite amount of potential energy as it were which can always command intellectual or physical labor. But money as a power is unlike all other kinds of power in that it is by judicious investment capable of yielding a constant supply

of energy in the way of interest without diminishing the original amount. It is therefore in the highest degree injudicious in the founding of an establishment to exhaust the source of its power by architectural displays not absolutely required and which may forever involve a continual expense from the remaining funds to keep them in repair. As a general rule the buildings of educational or scientific institutions should be gradually evolved from the experience and wants of the establishment, and not as is too frequently the case from *a priori* misconceptions of those who have no adequate idea of the uses to which the structure is to be applied. It should be impressed upon the public that *buildings* do not constitute an institution, and that reputation and usefulness in science do not flow from visible and tangible manifestations, but are the immaterial fruit produced by the spirit of an organization. I trust that millions of human beings yet unborn will be familiar with the intellectual results of your observatory, although a single inquiry may never be made as to the style of the building in which these results have been produced.

My advice then would be, first, if possible that the right man be procured for director; secondly, that the principal instruments be constructed under his supervision; and thirdly, that the operations be commenced in an inexpensive wooden building, which will be found better in many respects for physical and astronomical observations than one of stone and brick. The instruments could be insured, I should think, at a small premium, and in that case if destroyed by fire might be replaced by others embracing the improvements which may have been suggested in the meantime.

As an illustration of what I have just said in regard to the building, I may mention that on a visit to Mr. Lockyer I found him carrying on a series of observations which have challenged the admiration of the world in a temporary structure made of rough boards, unplastered, and scarcely including a space of fifteen feet square.

As to the location of your observatory, you will infer from what I have said that I think it important to connect it with some well-endowed and well-established college or university.

EFFECT OF THE MOON ON THE WEATHER.*

(From the Smithsonian Annual Report for 1871, pp. 460, 461.)

Since the form of the orbit of the earth is affected by the attraction of Venus and the other planets, as well as by its satellite the moon, they must in some degree also affect the form of the atmospheric covering of the globe, and tend to produce tides which are of greatest magnitude when they are in opposition to or in conjunction with the sun. But whether these disturbances of the atmosphere or those produced by the moon are of such a character as to give rise to the violent atmospheric commotions denominated storms, is a question which has long agitated the scientific world.

The times and peculiarities of the meteorological occurrences are more varied and less definitely remembered than almost any other natural phenomena, and hence the large number of different rules for predicting the changes of the weather. The only way of accurately ascertaining the truth of any hypothesis in regard to atmospheric changes, is that of having recourse to trustworthy records of the weather through a long series of years, and it is one of our objects in collecting meteorological statistics at the Smithsonian Institution to obtain the means of proving or dis-proving propositions of the character you have advanced.

The moon, being the body nearest to the earth, produces the highest tide in the waters of the ocean, and must also produce the greatest effect on the aerial covering of the earth. It has not been satisfactorily proved however that the occurrence of the lunar tides is connected with appreciable changes in the barometrical or thermometrical condition of the atmosphere. The less pressure of the air at a given place on account of the action of the moon, is just balanced by the increased height of the aerial column.

The principal causes of the violent changes of the atmos-

*[Letter to a correspondent in reply to inquiries and suggestions on the subject.]

phere are due I think to its instability produced by the formation and condensation of vapor. It is not impossible that when the air is in a very unstable condition on account of the heat and moisture of the lower strata, the aerial tide may induce an overturning of the tottering equilibrium at some one place in the northern or southern hemisphere more unstable than the others, and thus commence a storm which, but for this extraneous cause, would not have happened. To detect any such influence of the moon however, it will be necessary to compare simultaneously the records of the weather from day to day throughout all the northern and southern temperate zones, and to ascertain whether the maximum of these changes have any fixed relation in time to the changes of the moon.

The changes of the moon take place at a given moment on every part of the earth; the greatest effect of a lunar tide ought therefore to be felt in succession entirely around the earth in the course of about twenty-four and one-half hours.

The problem cannot be determined however by such casual observations as those which you narrate. I have not the least idea that the attraction of Venus produces any appreciable effect. It is too small to produce a result which would be indicated by any of our meterological instruments.

I am far from subscribing to the justice of your remarks in regard to Mr. Espy, since I have a great respect for his scientific character, notwithstanding his aberration, in a practical point of view, as to the economical production of rain. The fact has been abundantly proved by observation that a large fire sometimes produces an overturn in the unstable equilibrium of the atmosphere and gives rise to the beginning of a violent storm, but it was not wise in him to insist on the possibility of turning this principle to an economical use.

ON THE ORGANIZATION OF A SCIENTIFIC SOCIETY.*

(Bulletin of the Philosophical Society of Washington, vol. I, pp. v–xiv.)

Delivered November 18, 1871.

GENTLEMEN: I have been requested to make some remarks on the character and object of this Society which may serve to introduce it to the world through the pages of a Bulletin of its proceedings, or the public journals of the day, and in compliance with this request, I beg leave to submit the following reflections on the importance, as well as on the proper conduct of such an association.

This Society was formed by the call for a meeting of a number of gentlemen impressed with the importance of an association of a strictly scientific character, in the city of Washington. At the meeting which resulted from this call, a name and a constitution were adopted for the Society, and without delay, in a series of subsequent meetings, the objects of the association were prosecuted with such marked success, as to fully realize the anticipations which had been entertained with regard to the enterprise. This is manifest from the number, character, and variety of the communications presented and discussed.

In regard to the name which has been chosen, "THE PHILOSOPHICAL SOCIETY OF WASHINGTON," it is proper to remark that it was adopted not without considerable deliberation. The term "Philosophical" was chosen not to denote, as it generally does in the present day, the unbounded field of speculative thought, which embraces the possible as well as the actual of existence, but to be used in its restricted sense to indicate those branches of knowledge that relate to the positive facts and laws of the physical and moral universe. The second term, "Washington," was selected to denote the fact that the Society is a *local* establishment; that it arrogates to itself nothing on account of its position at the

* [Anniversary Address of the President of the Philosophical Society of Washington.]

national capital; makes no claim to any connection with the government, nor to being in any respect a special representative of the science of the country.

The importance of such a society must be evident to all who are acquainted with the history of science. It is mainly through the influence exerted and the assistance rendered by such associations, that science is advanced and its results given to the world. Man is a sympathetic being, and no incentive to mental exertion is more powerful than that which springs from a desire for the approbation of his fellow men; besides this, frequent interchange of ideas and appreciative encouragement are almost essential to the successful prosecution of labors requiring profound thought and continued mental exertion. Hence it is important that those engaged in similar pursuits should have opportunities for frequent meetings at stated periods. This is more particularly the case with the cultivators of abstract science who find comparatively few fully capable of appreciating the value of their labors, even in a community how much soever enlightened it may be on general subjects. The students of history, of literature, of politics, and of art, find everywhere men who can enter in some degree into their pursuits, and who can appreciate their merits and derive pleasure from their writings or conversation; while the mathematician, the astronomer, the physicist, the chemist, the biologist, and the student of descriptive natural history, meet with relatively few who can sympathize with them in their pursuits, or who have a sufficient knowledge of their particular subjects to be able to award them that intelligent appreciation and encouragement essential to their sustained and laborious efforts. To them, the world consists of a few individuals to whom they are to look for that critical judgment of their merits which is to be finally adopted by the general public, and with these it is of the first importance that they should have more frequent intercourse than that which arises from casual meetings.

Furthermore, a society of this kind becomes a means of instruction to all its members, the knowledge of each be-

coming as it were the knowledge of the whole. Again, there is a common bond of union between all branches of science, since they all relate to the existence and laws of the same universe in which the more we extend our knowledge the more we find of "unity in the midst of infinite diversity."

This connection is obvious in the relations of astronomy, mathematics, and physics, as well as in those of geology, chemistry, and biology, which are so closely related in many cases as to be separable only by conventional limits. In a society therefore like the one in question, embracing in its objects as it does—all branches of science, each investigator may find others cultivating fields separated from his own by insensible degrees, from whom he can have not only full sympathy and adequate appreciation, but also in many instances, important suggestions and essential aid.

The governing body of such a society, in order that the organization may produce the desired effect, must be largely composed of men who by education and experience in the processes of investigation, are justly entitled to the appellation of "scientific," and who from their positive contributions to the science of the day, are acknowledged by the scientific world as worthy of this distinction. It is true that useful societies are formed for the self-improvement of their members by the production of essays on various subjects, or by cultivation of branches of natural history requiring no previous special training; the city of Washington however needs something of a higher order, namely a society for the *advancement* of science, since in no other city in the Union are there so many men, in proportion to the population, connected with scientific pursuits, or so many facilities afforded for scientific investigation.

The Philosophical Society of Washington, though of a local and unostentatious character, if true to itself and its mission, may accomplish much towards increasing the reputation of the country and influencing public opinion with regard to questions of a scientific character. However wide the diffusion of general knowledge, public opinion in regard to scientific questions must eventually be determined by the

authority of societies, journals, and individuals, of established scientific reputation. It is therefore of the first importance that the operations of this Society be conducted with great care, and that nothing be given to the world under its sanction which is not based upon thorough investigation or established scientific principles. We should be warned by the fate of a society established in this city some thirty years ago, which although it included among its members a few men of true science, was under the control principally of amateurs and politicians, and therefore was unfit to discharge the duty which it claimed as one of its functions, to decide questions of a strictly scientific character. It should have been borne in mind by this association that votes on questions in science should be *weighed*, not counted! Had the proposition of the motion of the earth been decided in the days of Galileo by the popular voice, this philosopher and his friends would have been vastly in the minority. The society to which I allude, after achieving an unenviable notoriety, by assuming to be the arbiter of the science of the country, gradually sunk into oblivion, from which its memory should not be recalled except as a warning to those who would adventure in the same line.

It is an essential feature of a scientific society that every communication presented to it should be subject to free critical discussion. Such discussion not only enlivens the proceedings but is generally instructive, frequently eliciting facts which though insignificant when isolated, when brought together mutually illustrate each other and lead ultimately to important conclusions. The extent to which discussions may be allowed evidently depends on the candor and temper of those who engage in them. Among the things to be avoided are merely verbal criticism, undue harshness on the one hand and unmerited praise on the other, regard being had to truth rather than to victory or mutual adulation. There is nothing perhaps that marks more distinctly one of the characteristics of a true scientist than the manner in which he receives and appropriates to his use the critical remarks that may be made upon his

communications. He can (in many cases at least) derive from them the indication that he has failed to present on some points a clear statement of his investigations; or that in some other points his conclusions are not fully sustained by the premises. Unfortunately, it frequently happens that persons of a sensitive disposition are apt to consider criticisms of the kind we have mentioned as personal attacks, and feel that it is as offensive to doubt the accuracy of their experiments or conclusions, as it is to doubt their word. It should be recollected however that the most gifted are liable to err, and that these criticisms are *prior* to publication, and therefore of value to the permanent reputation of both the individual and the society.

Another important matter in regard to such a society is the publication of its proceedings. If its object were merely the intellectual and moral improvement of its members it might dispense with any publication whatever,—even with the announcement of its existence. If however it aspires to the more important office of *advancing* science or of enlarging the bounds of thought and assisting to diffuse a knowledge of new truths, it should then publish—if not quarto volumes of transactions—at least a bulletin of its proceedings. This publication should present an exposition of the organization of the society, its constitution and by-laws, give a list of the members, a synopsis of the contents of all communications submitted for consideration, and an account of important facts which may be elicited during discussions or recalled to memory at the moment by association of ideas.

Such a bulletin will enable the members of the society to publish without delay through a proper channel a synopsis of their investigations, and also minor facts and inferences not considered in themselves of sufficient importance to form a communication to a scientific journal or to occupy a place in philosophical transactions. Such facts are nevertheless frequently found to be valuable contributions to the general stock of knowledge. Were it possessed of the requisite funds the society might establish a higher reputation by the publication of independent transactions. Inasmuch as this is

not the case however, the next best plan should be adopted, namely, that of publishing papers in full through other channels, such for instance as the Smithsonian Institution, the reports of government bureaus, and scientific journals. In such cases the bulletin should contain references as to where the articles in full are to appear, and in this respect it would do good service in assisting to make more generally known the valuable contributions to science which are diffused through voluminous executive and congressional documents not readily accessible to the scientific world.

The editing of the bulletin should be under the direction of the secretaries and a committee appointed for the purpose, and a number should be issued as often as material of the proper character and of sufficient quantity is accumulated. It should be distributed to the principal learned societies of this and other countries, and may also be presented to leading journals in this and other cities. Without at least such a publication, the society cannot have a recognized existence.

I have stated that there is no city in the United States where, in proportion to the number of its inhabitants, there are so many men of education actively engaged in pursuits connected with science, as in Washington. In illustration of this remark I may refer to those who are engaged in the Coast Survey, the Office of Weights and Measures, the National Observatory, the Nautical Almanac Office, Patent Office, Engineer Department, Hydrographic Office, Ordnance Department, Medical Departments of the Army and Navy, Light-house Board, Signal Corps, Agricultural Department, Bureau of Statistics, Census Office, Bureaus of Navigation and Steam Engineering, the Smithsonian Institution, etc., etc. In addition to this, no city in the Union possesses more ample facilities, in the way of books and implements, for the prosecution of scientific research. The library of Congress, enriched by the Smithsonian Deposit with the transactions of all the principal learned societies of the world, is almost unrivalled in scientific works. If to this extensive collection we add the special libraries of the Patent Office, the Agricultural Department, the Coast Survey, the National

Observatory, and the Surgeon-General's Office, we have a collection of modern books on science, accessible to the members of the society, scarcely surpassed by the collections of the most favored cities of the old world. Nor are the articles of apparatus—necessary for any line of investigation—beyond the reach of any member of the Society who may possess the knowledge and skill requisite to their proper use. There is great liberality on the part of the heads of departments in regard to furnishing apparatus that may in any degree facilitate the special investigations under their direction.

Among those connected with the various organizations just mentioned, a considerable number is engaged in *original* investigations, the results of which are of interest to the scientific world, and which will be facilitated and improved by the discussions of this Society. Furthermore, in the daily operations of the different establishments, facts of scientific importance are continually becoming evident that would be lost if not preserved in the records of the Society. It is not however alone to facilitate operations now going on, or to preserve facts that may have been casually discovered, but also to suggest new investigations and to encourage others to enter the field of research who have not yet essayed their hand in this direction. In the great domain of science, there is abundant room for an indefinite number of laborers of different grades of attainment and original powers of mind. A series of careful observations made with proper instruments, with regularity and precision, (requiring little more than the exercise of the senses and a conscientious regard for truth,) is frequently a valuable contribution to science. A series of analyses in which prescribed formulas are observed, and in the application of which no more talent is required than that possessed by the majority of persons of ordinary ability and education, may give results of scientific value. For the production of results of the kind mentioned, and those which are effected by the scientist who is capable of detecting hitherto undiscovered facts and developing new laws, there is room for all grades of talent and of powers of original investigation. It is remarkable how

much may be done by the association of minds determined on a common pursuit; how much (under such conditions as exist in the city of Washington), may be effected in the way of directing attention to special lines of investigation, in suggesting questions to be asked of nature, and in pointing out the ready means by which the answers may be elicited, by arousing into activity talents that without such stimulus and suggestion would ever remain dormant.

The bane of many societies is the time consumed in details of business and in the discussion of non-essential points relative to their government. Happily, the organization adopted by this Society obviates this evil and secures the devotion of almost every evening exclusively to its legitimate purposes. For the government of men whose object is the advance of *truth*, but few rules are necessary, and these (unlike the laws of the Medes and Persians—expressed in inexorable codes) must consist of simple principles, readily adaptable to all contingencies.

In conclusion, I would say that with so many facilities as exist in the city of Washington for the pursuit of science, this Society would be derelict of duty did it fail to materially aid—through communion of thought and concert of action, the advancement of the great cause of human improvement. I am happy in cherishing the opinion however that the success of "The Philosophical Society of Washington" is scarcely any longer problematical, and in this I am sustained by the record of its transactions.

ON THE EMPLOYMENT OF MINERAL OIL FOR LIGHT-HOUSE ILLUMINATION.

(Report of the United States Light-House Board for 1875; pp. 5, 6.)

- - - During the year, the Board—under the personal direction of its chairman (assisted from time to time by other members of the Board), has made an extensive and careful series of experiments with regard to the merits of the mineral oils of this country for the purposes of light-house illumination. In order to obtain a great variety of oils, the Board—on November 24, 1874—advertised in various newspapers published in different parts of the United States, inviting manufacturers and dealers to furnish it with specimens of domestic mineral-oil for test as to their fitness for light-house purposes. As soon as a sufficient quantity had been received, the investigation was begun, and it has been continued, with results which lead to the belief that there can be had in this country an oil of suitable quality for light-house use, and perhaps at a considerable reduction in expense.

For the purpose of comparing our mineral-oils with those now coming into use abroad, the Trinity House authorities have been requested to send to the Board a specimen of that used in lights under their control: and when this is obtained, which is expected to be soon, further experiments will be made. While with its present knowledge of the qualities of these oils, the Board proposes to put them into use at light-stations on the mainland, it would hesitate to endanger valuable property, and the lives of its employés, by placing them on board of light-ships, in structures standing in the water, or at other points from which the keepers could not escape in case of accident.

INVESTIGATIONS RELATIVE TO ILLUMINATING MATERIALS.

(Report of the United States Light-House Board for 1875; pp. 86–103.)

Preliminary Remarks.

It has been the policy of the Light-House Board since its first establishment not only to adopt the latest improvements that have been made in other countries, but also to add by original investigations to the sum of knowledge respecting aids to navigation. In accordance with this policy, the Board has endeavored to keep itself informed as to the progress of the light-house systems of other countries, and in the erection of new towers and the supply of new apparatus, to adopt those improvements which have from actual experience been preferred; and furthermore, the committee on experiments has devoted a portion of every year to investigations which might develop new facts tending to greater economy or efficiency in the various appliances by which the dangers of navigation are diminished.

At the commencement of the operations of the Light-House Board, in 1852, sperm oil was generally employed for the purpose of illumination. This was an excellent illuminant, but as its price continued to advance from year to year, it was thought proper to attempt the introduction of some other material. The first attempt of this kind was that of the introduction of colza oil, which was generally used in the light-houses of Europe:—an oil extracted from the seed of a species of wild cabbage, known in this country as rape, and in France as colza. For this purpose a quantity of rape-seed was imported from France and distributed—through the agricultural department of the Patent Office, to different parts of the country, with the hope that our farmers might be induced to attempt its cultivation. Although the climate of the country appeared favorable to its growth, and special instructions were prepared and distributed by the Light-House Board—for its culture and the means of producing oil from it, yet the enterprise was not undertaken with any ap-

proximation to success, except in Wisconsin, where a manufactory of rape-seed oil was established by Col. C. S. Hamilton, formerly of the United States Army. To this manufactory the Light-House Board gave special encouragement, and purchased at a liberal price—all the oil that could be supplied: the quantity however which could be procured was but a small part of the illuminating material required by the annual consumption of the Light-House establishment.

The price of sperm oil still continuing to increase, the Board employed Prof. J. H. Alexander, a chemist of Baltimore, to make a series of investigations on different oils, to ascertain a method of detecting adulterations in them, and to determine the relative economical value of different kinds of oil which might serve for use in light-houses. In his report Prof. Alexander recommended—as a means of detecting adulterations in oil, a thermal test based upon the amount of heat evolved by mixing a given quantity of the oil with sulphuric acid of a given specific gravity, and noting the rise of temperature as indicated by a standard thermometer in a unit of time. For using this method, it was proposed to ascertain by actual experiment—the heat evolved by mixing pure oils with a given quantity of acid, and afterward oils adulterated with given quantities of lard or inferior oils. This ingenious suggestion was however never reduced to practice. The method was too refined; the difference of heat evolved was scarcely sufficient to be noted unless great precautions were taken to prevent loss by radiation and conduction, and consequently it could not be employed by ordinary inspectors. In regard to lard oil, Prof. Alexander—not having ascertained the best conditions for burning it, consequently rated it very low in the scale of economical value as a light-house illuminant.

In this stage of the history of the subject, the chairman of the committee on experiments commenced himself to investigate the qualities of different kinds of oil, and was soon led to direct his attention to the comparative value of sperm and lard oils. The experiments made by Prof. Alexander

were with small lamps, and the comparison in this case, as will be shown, was much against the lard oil.

Experiments on Lard Oil.

The first experiment of the new series consisted in charging two small conical lamps of the capacity of about a half pint, one with pure sperm oil and the other with lard oil. These lamps had single-rope wicks, each containing the same number of strands; they were lighted at the same time, and the photometrical power ascertained by the method of shadows. At first the two were nearly equal in brilliancy, but after burning about three hours the flame of the lard oil had declined in photometric power to about one-fifth of that of the sperm oil. The question then occurred as to the cause of this decline, and it was suggested that it might be due—first, to a greater specific gravity in the lard oil, which would retard the ascent of it in the wick, after the level of the oil had been reduced by burning in the lamp; or second, to a want of sufficient attraction between the oil and the wick to furnish the requisite supply as the oil descended in the lamp; or third, it might be due in part to the imperfect liquidity of the oil, which would also militate against its use in mechanical lamps.

The lard oil was subjected to experiments in regard to each of these points. It was found—by the usual method of weighing equal quantities of the two fluids, that the specific gravity of the lard oil was greater than that of the sperm oil.

It was also found—by dipping two portions of the same wick into the two liquids and noting the height to which each ascended in a given time, that the surface attraction of the sperm oil was greater than that of the lard oil, or in other words the ascensional power of sperm oil was much greater than that of lard oil at ordinary temperatures. This method was also employed in obtaining the relative surface attraction of various other liquids. I say surface attraction instead of capillarity, because it was found in the course of these investigations that substances which had less capillarity (that

is less elevating power in a fine tube) had sometimes greater power in ascending in the meshes of a wick.

The relative fluidity of the different oils was obtained by filling with them in succession—a pear-shaped vessel of about the capacity of a pint, with a narrow neck, and having a hole in the lowest part of the bottom of about a tenth of an inch in diameter. Such a vessel filled with any number of perfect liquids would be emptied in the same time, whatever their specific gravity. As at any given horizon inertia is directly proportional to gravity, the heavier the liquid the greater would be the power required to move it; but the motive power would be in proportion to the pressure, or in other words to the weight, and therefore all perfect liquids should issue from the same orifice with the same velocity. To test this proposition, eight fluid ounces of clean mercury, and then the same bulk of distilled water, were allowed to run out of the vessel above mentioned; the time observed was the same within the nearest second. It was found in repeating this experiment with sperm and lard oils that the rapidity of the flow of the former exceeded considerably that of the latter, the ratio of time being 100 to 167.

The results thus far in these investigations were apparently against the use of lard oil; it was observed however in the experiments on the flow of the two oils on different occasions that a variation in the time occurred, which could be attributed only to a variation in the temperatures at which the experiments were made. In relation to this point, the effect of an increase of the temperature above that of the atmosphere—on the flowing of the two oils, was observed. By this means the important fact was elicited that as the temperature was increased, the liquidity of the lard oil increased in a more rapid degree than that of the sperm oil, and that at the temperature of about 250° F. the liquidity of the former exceeded that of the latter.

A similar series of experiments was made in regard to the rapidity of ascent of the oil in the wick, and with a similar result. At about the temperature just above mentioned, the ascensional power of the lard oil was greater than that of

the sperm oil. These results were recognized as having an important bearing on the question of the application of lard oil as a light-house illuminant. It only required to be burned at a high temperature, and as this could be readily obtained in the case of larger lamps, there appeared to be no difficulty in its application.

The previous trials had been with small lamps with single solid wicks, instead of the Fresnel lamp with hollow burners. After these preliminary experiments two light-houses of the first order at Cape Ann, Massachusetts, (separated by a distance of only 900 feet,) were selected as affording excellent facilities for trying—in actual burning, the correctness of the conclusions which had been arrived at. One of these light-houses was supplied with sperm oil and the other with lard oil, each lamp being so trimmed as to exhibit its greatest capacity. It was found by photometrical trial that the lamp supplied with lard oil exceeded in intensity of light that of the one furnished with sperm oil. The experiment was continued for several months, and the relative volume of the two materials carefully observed. The quantity of sperm oil burned during the continuance of the experiment was to that of lard oil as 100 is to 104.

The freezing temperature of lard oil depends upon the temperature at which it was expelled by pressure from the animal tissues in which it was contained. It is higher however than the freezing temperature of sperm oil, on an average of from 3° to 4° F., but this is a matter of no practical objection to the substitution of lard oil for sperm oil, since the heat evolved from an Argand lamp is—in cases where the draught passes through the reservoir, sufficient to keep the lard oil liquid even during the lowest external temperature. Indeed, the small difference in temperature in freezing of the two oils is a matter of little moment in cases which frequently happen when the temperature of the atmosphere is below zero on the Fahrenheit scale. At such a temperature both oils would alike become solid unless some means were afforded for preventing the freezing.

The next step toward the introduction of lard oil was the

devising of a system by which it could be inspected, and the Board assured—before it should be too late to remedy the evil, that the lard oil purchased was of a good quality. This was a matter of great importance, and involved no small degree of responsibility, since the contractor was entitled to his pay immediately after the acceptance of the oil; and the quantity purchased amounted annually to nearly 100,000 gallons.

The conclusion was arrived at that it was impossible—from any single test that could be applied to small samples, to determine the quality of the oil as applicable to light-house purposes, and that in the present state of our knowledge as to its character, the following tests are required to fully insure in all cases the required quality of the article:

1. Specific gravity at 60° F.
2. Liquidity at different temperatures.
3. Freedom from acids or alkalies.
4. Resistance to freezing.
5. Actual burning in fifth-order lamps for at least ten hours.
6. Photometric power after burning one hour, and again after burning ten hours.
7. The condition of the wick at the end of the burning.

These tests are of very unequal value, and several of them might be dispensed with, were others reduced to an absolute standard—determined by the actual experience of burning in the light-houses.

The specific gravity of impure lard oil and of that which has been carefully refined—differ but little, and hence unless the experiment be made by means of a delicate balance, the indications will be of comparatively little value. Still, as a given sample might contain some foreign substance which is not usually mixed with this oil, the test with the hydrometer should not be omitted.

In making this test, a cylindrical vessel containing the oil—of sufficient diameter to permit the hydrometer to float freely without hindrance from the sides, should be immersed in a vessel containing several gallons of water, which when

once reduced to 60° by the addition of ice-cold water, can (on account of the great specific heat of water,) be readily kept at that temperature by a slight addition of cold water from time to time, the whole being continually stirred. It is scarcely necessary to state that the vessel containing the oil must be so weighted at the bottom that it will stand erect in the cold bath in which the experiment is made.

Liquidity at different temperatures is a test similar in character to that of specific gravity; although the difference in degree of liquidity of different kinds of oil, such as sperm, whale, and lard, is very considerable, the difference between different samples of lard oil is small. Still this test (for a similar reason to that given for the specific gravity,) should be applied.

The test for free acids and alkalies is easily made, and should in no case be omitted. A portion is put into beaker-glasses, with a slip of litmus-paper in one and a slip of turmeric paper in the other, and suffered to remain immersed perhaps twenty-four hours; and at the end of that time, if one of these papers exhibits no redness and the other no brownness, the oil may be considered void of free acid and of alkali,—either of which would lessen its value, the former tending to corrode the lamp, and the latter interfering with the burning quality.

Resistance to freezing is an important test, but not as easily applied in the case of lard-oil as might at first be imagined. Lard-oil possesses the remarkable property of resisting the influence of a low temperature if suddenly applied, while it will freeze at a much higher temperature if the cold be continued for several hours.

For example if a small portion of lard oil be placed in a test-tube and submitted to a rapid diminution of temperature by being plunged in a freezing-mixture, it will remain liquid for some time at a temperature of 19° or 20°, whereas it will congeal at a temperature of 40° if suffered to remain at that temperature for several hours.

The plan adopted for determining the freezing-point of different samples of oil, at one operation, consisted in making a series of small openings or windows, closed with

glass, in the side of a cylindrical wooden tub about 2½ feet in diameter. Concentric within this tub was placed another cylindrical vessel (of smaller diameter) of zinc, filled with a freezing-mixture of salt and pounded ice. A series of small beaker-glasses, filled with the several samples of oil, was placed opposite the windows in the space between the two cylinders, each containing a thermometer which could be read through the window. The whole was then inclosed by a tightly-fitting cover, through which projected the handle of a crank, by which the freezing-mixture could be stirred. The samples of the oil subjected to this cold-air bath gradually passed through the several stages of diminution in limpidity and clearness—to opacity and solidity, the time of each being noted.

The most reliable test is that of actual burning in a lamp of the fifth order and the measurement of the photometrical power. The objection to the application of this test to the oil of every barrel is the large quantity of oil required and the amount of labor involved in the proper execution of the process. Thus in testing 60,000 gallons contained in casks of forty gallons each, at least 500 gallons would be required. It is therefore evident that this test can only be applied to samples selected from a given lot, while the single barrels are proved to be of a similar character by the more simple tests.

Another method of insuring that all the casks of a given lot contain oil of the same quality consists in taking a small equal portion from each of several casks and mingling them together, the quality of the compound being ascertained by the application of burning or the other tests.

The determination of the photometrical power is in the present state of science (unless great precaution is observed), a problem of some uncertainty. The difficulties are of two kinds, the first to find a photometer which shall give the ratio of the two lights, and second, to find an invariable standard to which oil of the proper quality may always be referred.

These difficulties can I think be sufficiently overcome for the practical purposes of the Light-House Board. The greater difficulty is that of obtaining a standard of reference.

For this a sample of lard oil manufactured by Mr. Alden, of Boston, was at first employed, but this itself was found to be variable, and hence we were obliged to adopt some other standard. The one which has been finally adopted is the English sperm candle, which burns with considerable uniformity at the rate of 120 grains per hour, or two grains per minute.

In regard to the investigation, the experiments were carried on under many difficulties. They were made at first in the engineer's office of the second light-house district in Boston, with such appliances as could be procured at the moment, with the assistance of Mr. William Goodwin, the acting light-house engineer, who took much interest in the subject and rendered efficient service.

In the erection of a new lamp-shop at the Staten Island depot, care was taken to make provision for a dark room in which the photometrical examinations could be made with more precision than had been obtained in the temporary apartments previously used. This room extends the whole length of the building, is about 80 feet long by 12 wide; the windows are closed by iron shutters to exclude the light; and the walls, floor, and all other parts are painted black, after being sanded to remove any glare which might exist.

In the first experiments on lard oil the photometrical process employed was that of Rumford, which consists in ascertaining the relative intensity of two lights from their distances from a screen on which shadows of equal darkness are thrown by an intermediate body. In this case the relative intensities sought are indicated by the square of the distances in inches and parts of inches of each light from the screen on which the shadows are cast. But this method, which is used by the French manufacturers of apparatus, and is very simple in theory, does not admit of much accuracy.

The arrangement therefore known as Bunsen's photometer was introduced in its stead, and this (with some peculiar modifications) leaves nothing to be desired. This arrangement consists in placing two lights at the extremity of a scale so divided into distances that the relative intensity of

the two flames may be immediately read off in terms of candle-power, when a small intermediate movable screen is equally illuminated on both sides. This screen is usually formed of a piece of white pasteboard of about four inches square, fixed perpendicularly at right angles to the length of the scale in a sliding frame, by which it can be brought nearer to or farther from one of the lights. In the centre of this square is a circular hole of about half an inch in diameter which is closed by a piece of thin paper, rendered translucent by a solution of spermaceti in oil of turpentine. This forms a spot which is darker than the other parts of the white screen, and is equally dark on both surfaces when the screen is receiving an equal quantity of light from each flame; the screen is moved backward and forward until this effect is produced, and the index will then point on the graduated scale to the number of the relative power of one of the lights in the terms of the other.

The screen may also be made of thin paper, the whole of which is rendered translucent except a round spot in the centre of half an inch in diameter. If a light is placed before the screen on one side, the whole of the greased part will appear dark, on account of part of the light going through the translucent portion. If now another light be placed on the opposite side an equal portion will be transmitted through the pellucid part, and the two surfaces will appear of like intensity when the two lights are equal, or when from their respective distances they throw equal amounts of light on the two faces of the screen.

In order that both sides may be seen at the same moment without moving the head from one edge of the screen, two mirrors making with each other an angle of 90° are placed so that the screen itself will bisect the angle.

For dividing the scale into parts related to each other as the square of their distances from a centre, the following formula and table will furnish the means. Let a be the length of the scale, and x the distance from the candle end to the movable screen; then $a—x$ is the distance between the lamp end and the screen. Denote the degree of illumination on the candle and lamp sides of the screen

by L and L' respectively. Let the intensity of the candle end equal one candle, while that of the lamp is n candles. Then, since the illumination of the screen varies directly as the intensity and inversely as the square of the distance, we have the following proportion:

$L : L' :: \frac{1}{x^2} : \frac{n}{(a-x)^2}$, and when $L = L'$ we have $(a-x)^2 = nx^2$ whence $x = \frac{a}{1+\sqrt{n}}$. For convenience of using this formula it is best to change its form into $x = a\,\frac{\sqrt{n}-1}{n-1}$.

The following table has been computed by calling the length of the scale 100 and assigning successive integral values to n, from 1 to 100. The column A shows the value of $a-x$ for each assumed value of n:

Table of distances and candle-powers.

Number of candles.	A	Number of candles.	A	Number of candles.	A	Number of candles.	A
1	50·00	26	16 40	51	12·28	76	10·29
2	41·42	27	16·14	52	12·18	77	10·23
3	36·60	28	15·89	53	12·08	78	10·17
4	33·33	29	15·66	54	11·98	79	10·11
5	30·90	30	15·44	55	11·88	80	10·05
6	28·99	31	15·23	56	11·79	81	10·00
7	27·43	32	15·02	57	11·70	82	9·94
8	26·12	33	14·89	58	11·61	83	9·89
9	25·00	34	14 64	59	11·52	84	9·84
10	24·03	35	14·46	60	11·43	85	9·79
11	23·17	36	14·29	61	11·35	86	9·73
12	22·40	37	14·12	62	11 27	87	9·68
13	21·71	38	13·96	63	11·19	88	9·63
14	21·08	39	13·80	64	11·11	89	9 58
15	20·52	40	13·65	65	11·04	90	9·54
16	20·00	41	13·51	66	10·96	91	9·49
17	19·52	42	13·37	67	10·89	92	9·44
18	19·07	43	13·23	68	10·82	93	9·40
19	18·66	44	13·10	69	10·75	94	9·35
20	18·27	45	12·97	70	10·68	95	9·31
21	17·91	46	12·85	71	10·61	96	9·26
22	17·58	47	12·73	72	10·54	97	9·22
23	17·25	48	12·61	73	10·48	98	9·17
24	16·95	49	12·50	74	10·41	99	9·13
25	16·67	50	12·39	75	10·35	100	9·09

The standard adopted with which to compare all other lights is (as we have said) that of the London sperm candle, which (under ordinary conditions) burns 120 grains of sperm per hour. If it burns more or less than this amount during the trial, a correction of a proportional amount is made in the results.

This standard however is too small for determining the power of large lamps, and for this purpose an intermediate standard is provisionally adopted. For example—in determining the power of a lamp of the first order, the power of a lamp of the fourth order is first obtained, and this is used as a comparison with the larger lamp.

In the case of the arrangement—at the Staten Island depot, for photometrical measurements, three scales are employed, diverging from a centre at which the lamp to be measured is temporarily placed; at the farther end of each scale is placed a sperm candle to serve as the standard of comparison. These scales are of different lengths, one being 100 inches in length, another 150 inches, and the third 200 inches; besides these, one of the scales is occasionally replaced by one of 700 inches in length, which is put up in sections.

As the semi-diameter of the burner of the lamp and that of the candle must be included in the length of the scale, a portion of the latter at each end is cut off. In adjusting the scales therefore to their places, the measurement must be taken from the middle of each scale; thus in the case of the one of 200 inches in length, the middle of it must be just 100 inches from the centre of the lamp on one side and 100 inches from the centre of the candle on the other. In making the examination, three observers (one at each scale) simultaneously take the photometric readings, and the mean of the three results is adopted as the candle-power of the light under examination.

In the examination of oil previous to purchase, (as before stated,) a lamp of the fifth order is charged with the oil in question, and when in a state of equilibrium of combustion—is subjected to the trial. For greater precision ten read-

ings are taken on one side of the scale, and then the photometer is reversed and as many taken from the opposite side. In this way the mean of sixty readings, twenty on each scale, furnishes the data on which the character of the oil principally rests. As a means of simultaneously weighing the candles for checking the effects of their irregular burning, three balances are provided, each of which bears one of the candles in a socket supported by a metallic link, through which the scale-beam passes and is attached to the hook of the scale-pan below.

On the opposite scale-pan a series of grain weights are placed, which can be taken off by a pair of pincers without disturbing the equilibrium of the scale; the interval of time during which a given grain weight is burned is marked by a watch. If the interval is equal to two grains for each minute, the candle is burning at its normal rate; if not, a correction is made by simple proportion, which is applied to the measurement previously obtained.

The lamps containing the oil for trial are lighted and trimmed in an adjoining apartment. They are introduced into the dark room through a window closed with a sliding shutter. In order to prevent an overflow of oil at the burner by the oscillation of the liquid in the reservoir by the agitation of transfer, each lamp is placed on a small carriage moving on a railway passing through the window, which enables the lamp to be placed in its position with rapidity, and without the slightest disturbance of the equilibrium of the oil.

The temperature of the room is also noted, and as far as possible it is kept at a heat of not far from 70°. For this purpose—during warm weather, the inspection may be made at night.

For reading the divisions on the scales in the dark room, a mirror is employed to throw the light of the lamp under inspection on the graduation.

To exclude all extraneous light, the three candles and the lamp to be tested—are each surrounded by a cylindrical sheet-iron screen painted black, through which a hole (a little larger than the flame) allows the light to pass along the scale

to the photometer. The trial-lamps are those of the fifth order. Each (after it has been lighted) is allowed to burn an hour before being submitted to the photometrical measurement. If it gives a power less than 8 candles, the oil is rejected. If it passes that test, it is allowed to burn undisturbed without being trimmed—for 8 or 9 hours longer, and if it is found at the end of that time to exhibit no diminution in the brilliancy of the light, it is considered worthy of adoption, especially if after this it continues to burn 4 or 5 hours additionally with no perceptible diminution that can be detected with the naked eye. The best lard oil will burn 16 hours without trimming.

Each candle before the measurement commences is suffered to burn until it has assumed a perfect and uniform rate of consumption: it should be prevented from guttering by removing a portion of the melted spermaceti which may accumulate in the cup at the top of the candle beyond the power of the feeble incipient flame to consume,—by absorbing it with one end of a strand of candle-wick cautiously introduced. If any portion of the spermaceti is suffered to run down the side of the candle and drop off below, the correction for variation in burning will be worthless.

All materials for the use of the Light-House Establishment are purchased by contract in accordance with published specifications as regards quality and certain conditions. The award is given to the lowest bidder, provided he can offer trustworthy surety as to his ability to fulfill the contract. When bids are equal, or nearly so, preference however is given to the bidder who is a manufacturer of the oil, and not a mere vender of the article. During the inspection, permission is granted to the contractor to be present at the operation, in order that he may be assured that full justice is done him in the examination. After seeing the precision with which the photometric and other processes are conducted, he is generally fully satisfied as to the results obtained, even though his oil may have been rejected.

The oil is delivered in iron-bound casks, varying from 38 to 50 gallons. These are placed (previous to inspection) under a shed and arranged in different lots, each containing

oil of the same quality. From different casks samples are taken in tin canisters of a capacity of about half a gallon, each canister being marked with the number of the lot and the cask from which the oil was taken. Before the sample is drawn from the cask the oil within is thoroughly mixed by rolling the cask or by stirring. The object of this is to obtain in the sample an average amount of solid matter which may be contained in the oil.

The purest lard oil is that which is manufactured by submitting the solid leaf lard to great pressure during the coldest period of winter. Oil of this quality is used for burning in small mechanical lamps; it gives a bright flame and does not incrust the wick. The light-house lamps however—being of a much larger size and evolving a much greater amount of heat, can consume oil of a coarser character; and indeed it has been found that oil containing a certain amount of solid matter, provided the latter is not too much in quantity to be consumed by the lamp, gives a higher illuminating power. On this account—before this fact was generally known in the trade, complaints were made of the Light-House Board giving the preference to oil which in the market would not be considered of the first quality.

The quantity of oil is estimated by weight, allowing 7·6 pounds per gallon. It is weighed in gross and afterwards emptied into large tanks in an under-ground vault. The empty barrels are next weighed; the weight of these deducted gives the net weight of the oil.

Previous to the establishment of the general light-house depot at Staten Island, from which all the supplies are now distributed, and where the lamps and other light-house appliances are prepared for immediate use, the oil was received at various ports along the coast in accordance with terms of the contract, and was stored until wanted for use, in cellars hired for that purpose.

After the introduction of lard oil however, the board constructed a spacious under-ground receptacle capable of containing 50,000 gallons of oil, and retaining it during the whole year at a temperature not to exceed 65° Fahrenheit.

The under-ground vault contains five tanks, each of the

capacity of ten thousand gallons. On each tank is a register, consisting of a glass tube so divided as to give the contents in hundreds of gallons. The oil is delivered in three installments: The first on the 1st of May, the second on the 10th of June, and the third on the 22d of July. The vault and tanks were constructed under the direction of General Poe while engineer secretary of the board, who took a lively interest in the introduction of lard oil and in the preliminary experiments for determining its quality.

A photometer room was afterwards fitted up in the Smithsonian Institution, in which several series of investigations were made in regard to the illuminating power of different oils. At the same time a series of experiments was undertaken relative to their chemical characters and conditions, in which experiments the chairman was assisted by Prof. C. M. Wetherill whose untimely death the science of this country has been called to mourn. Among the investigations in the laboratory, are those given in the following table, relative to the expansions of different oils—intended to facilitate the purchase, the measurements being made at different temperatures. To obviate the necessity of the correction for temperature, the oil is now purchased by weight. The following results may however be of value in the application of different oils to light-house purposes:

Experiments upon Light-House Oils.

[Density and volume of oils (and water) at different temperatures.]

Temperature, C.	Sperm oil.		Whale oil (unrefined).		Lard oil (refined).		Lard oil (unrefined).	
	Volume.	Density.	Volume.	Density.	Volume.	Density.	Volume.	Density.
4°	1·0000	0·89256	1·0000	0·92825	1 0000	0·92488		
10°	1·0053	0·88783	1·0049	0·92370	1·0042	0·92103	1·0000	0·92086
15°	1·0095	0·88418	1·0095	0·91952	1·0093	0·91632	1·0051	0·91614
20°	1·0134	0·88072	1·0145	0·91498	1·0124	0·91356	1·0109	0·91090
25°	1·0168	0·87778	1·0166	0·91311	1·0164	0·90992	1·0146	0·90760
30°	1·0208	0·87432	1·0200	0·90999	1·0204	0·90641	1·1169	0·90556
35°	1·0243	0·87139	1·0236	0·90388	1·0237	0·90351	1·0204	0·90247
40°	1·0236	0·86721	1·0297	0·90146	1·0278	0·89986	1·0244	0·89897

Experiments upon Light-House Oils—Continued.

[Density and volume of oils (and water) at different temperatures.]

Temperature, C.	Kerosene.		Water (C. M. W.)		Water (Kopp).		Alcohol (Pierre), vol. at 0° C. = 1 vol.	
	Volume.	Density.	Volume.	Density.	Volume.	Density.	C.	Density.
4°	1·0000	0·81199	1·00000	1·00000	1·0000	1·00000	0°	1·0000
10°	1·0050	0·80799	1·00048	0·99952	1·0003	0·99975	10°	1·0107
15°	1·0106	0 80347	1·00086	0·99915	1·0008	0·99918		
20°	1·0152	0·79984	1·00176	0·99824	1·0017	0·99831	20°	1·0217
25°	1·0187	0·79709	1·00303	0·99698	1·0028	0·99717		
30°	1·0234	0·79346	1·00447	0·99555	1·0042	0·99579	30°	1·0331
35°	1·0276	0·79020	1·00619	0·99384				
40°	1·0321	0·78674	1·00774	0·99232	-------	--------	40°	1·0448

Chemical Analysis of Light-House Oils.

No. 1.—*Refined winter-pressed lard oil.*

	First experiment.	Second experiment.	Mean.	By calculation.
Carbon	76·87	76·53	76·75	C_{44} 76·74
Hydrogen	11·58	11·63	11·61	H_{40} 11·63
Oxygen	---------	---------	11·64	O_5 11·63
			100·00	100·00

No. 2.—*Crude lard oil.*

	First experiment.	Second experiment.	Mean.	By calculation.
Carbon	77·07	76·70	76·88	
Hydrogen	11·72	11.69	11·71	
Oxygen	---------	---------	11·41	
			100·00	

No. 3.—*Sperm oil.*

	First experiment.	Second experiment.	Mean.	By calculation.
Carbon	79·52	79·41	79·46	C_{53}—79·70
Hydrogen	12·28	12·28	12·28	H_{49}—12·28
Oxygen	---------	---------	8·26	O_4— 8·02
				100·00

Experiments of Mixing Oils with Oil of Vitriol of 66° Beaumé, at 62° F.

[Of oil, 2 fluid ounces; of sulphuric acid, 1 fluid ounce.]

First experiment.—Winter-pressed lard oil.

Temperature of oil before mixing	70° F.
Temperature of oil after slow mixing	130°
Difference	60°
At the expiration of 3 minutes, temperature	134°
At the expiration of 4 minutes, temperature	134°

Second experiment.—Winter-pressed lard oil.

Temperature before mixing	70° F.
Temperature after mixing rapidly	169°
Difference	99°

Third experiment.—Winter-pressed lard oil.

Temperature before mixing	70° F.
Temperature after mixing	165°
Difference	95°

Fourth experiment.—Crude lard oil.

Temperature before mixing	66° F.
Temperature after mixing	164°
Difference	98°

Refrigeration of Oils.

Those experimented upon were whale, sperm, refined lard, and crude lard oils.

First experiment.—At 30·2° F. they were all sirupy; in the crude lard oil a yellowish solid began to separate.

At 26·6° the sperm oil began to solidify.

At 24·8° the refined lard oil began to yield a white precipitate.

At 17·6° the whale oil was a thick sirup, without deposit. The crude lard oil was quite hard. The pure lard oil was not as hard as the crude lard oil. The sperm oil was not as hard as the pure lard oil. These experiments performed in test tubes.

Second experiment.—Upon pure winter-pressed lard oil, in a test tube.

At 17·6° F., it begins to deposit flakes of solid matter.

At 14° it is quite thick.

At 10·4° it is perfectly solid.

If now the temperature rises, a small portion of the oil remains solid until the temperature reaches 44·6°.

Third experiment.—The oils were placed in large cylinders and exposed to a temperature of 24·8° F., with the following results:

1. Crude lard oil, much sediment.
2. Sperm oil, ditto.
3. Pure refined lard oil, a little sediment.
4. Winter-strained lard oil, very little sediment.
5. Whale oil, no sediment.

In the use of sperm oil, it was found that the purer it could be obtained the better, and hence it was the custom to strain the oil (and also the drippings) through clean white sand previous to using it. In the case of lard oil however, (as before stated,) it was found that removing all the solid matter diminished its photometric power.

All fatty oils absorb oxygen, which unites with them to form oxides of their combustible ingredients; accordingly oil freely exposed to the air must in time gradually diminish in its power of combustion. It should therefore not be open to the atmosphere when the oil is to be stored, but covered with a thin wooden plane which floats upon the surface of the oil and thus in a great measure excludes the air. The freezing of lard oil does not appear to affect its quality.

Considerable difficulty was experienced in the introduction of lard oil on account of the objection to it on the part of the keepers; in some cases from the want of experience in using it, and in others from the interference of venders of sperm oil. This difficulty however was obviated by a resolution of the board, by which any keeper who declared his inability to burn lard oil should be requested to resign, since it had been abundantly proved that this oil with proper management could be made to compete favorably with sperm oil. Its introduction was a matter of great importance in an economical point of view; it saved the Government $100,000 annually for several years.

Another important step in the introduction of lard oil was that of furnishing a lamp which would burn it with the greatest perfection. This was effected by the invention of Mr. Joseph Funck, foreman of the lamp-shop. In order to burn

lard oil, it is necessary (as has been said) that it should be kept at a high temperature, and for this purpose the heat of the draught of the lamp was passed through the centre of the reservoir.

Previous to the change in the illuminating material there had been used in the light-house establishment three classes of lamps, viz, the mechanical lamp for the first, second, and third orders, and the moderator and fountain lamps for the fourth, fifth, and sixth orders.

In the mechanical lamp the oil was placed in a reservoir below the burner and pumped up by means of clock-work. This apparatus is of a complicated character, and is subject to derangement. The valves must be renewed from time to time and the clock-work cleaned. The proper performance of these operations is beyond the skill of an ordinary keeper, and requires the frequent service of a trained and expert attendant.

The moderator lamp is less complicated, and was invented to obviate the difficulties just mentioned. In this the oil is elevated by the descent of a heavy piston, and forced up through a small conical hole, the flow being regulated by the conical end of a wire, which is gradually withdrawn as the weight descends, so as to give a less obstructed flow as the hydrostatic pressure of the oil increases. From this arrangement it takes its name of moderator lamp. This apparatus however is liable to irregularity on account of derangement of the supplying apparatus, the varying friction of the packing of the piston, as well as the change in the flow of the oil, owing to its diminished liquidity on a reduction of its temperature.

The reservoir of the fountain lamp consists in an air-tight vessel, (usually cylindrical,) from the bottom of which descends a tube, terminating at the open end in a small cup, from which the burner is directly supplied with oil on the well-known principle of the bird fountain, this vessel being filled with oil by inverting it and pouring in the liquid through the open end of the tube. It is then re-inverted and the end of the tube inserted in the small cup below the level of the

oil which it contains. The oil in the reservoir in this condition is supported by the pressure of the atmosphere on the surface of the oil in the cup. When this surface is lowered by burning, the end of the tube is opened, and a bubble of air passes up and an equal bulk of oil descends, and in this way a nearly constant level of oil is maintained. I say nearly constant because the air which goes up is of some volume and in the act of passing up produces an oscillation which in some degree affects the steadiness of the flame.

There is however a greater defect in this lamp from the oscillations in the level when the reservoir has been exhausted of a considerable portion of its charge of oil. In this case the arrangement is one similar to an air thermometer with a large bulb, and is affected by a sudden draught produced by the opening and shutting of a door or the ordinary ventilation of the lantern. This was partly remedied by bending the tube, and thereby increasing the resistance to a sudden change in the level of the oil.

The improvement of Mr. Funck consisted in substituting for these lamps one of constant level, in which the oil is placed above the burner, and the flow of oil necessary for perfect combustion is regulated by a small floating piston, placed in an enlarged portion of the supply-tube, and carrying on its upper surface a conical projection which increases or diminishes the size of the supplying orifice in accordance with the rapidity of combustion. This lamp is not only free from the objections pertaining to the other lamps, but is less expensive and better adapted to the burning of lard oil. It affords a freer combustion, and consequently a more intense light, though at the cost of a larger amount of the burning material.

In this lamp the heated air and products of combustion pass through a cylindrical opening in the reservoir, which is placed directly above the lamp, the opening in it forming as it were a prolongation of the chimney, thus not only preventing the oil from freezing in the coldest weather, but supplying it to the burner at the temperature best adapted for perfect combustion.

Established Superiority of Lard Oil.—In regard to the comparative character of lard and colza oils we may be allowed to print the following letter from Colonel Hamilton, the manufacturer of the latter oil, who was present at the trial to which he alludes:

FOND DU LAC., WIS., *May* 16, 1868.

DEAR COMMODORE: I must confess my great disappointment at the result of the experiments at Staten Island. It is however not really so much the failure of rape-seed oil as the undeniable excellence of lard oil as a burner. I fully believe that our rape-seed oil of this year is as good as any that was ever made in Europe, and I know it is far better than any we have ever before made. I am satisfied now that for self-heating lamps there is no oil that will bear comparison with lard, but I am equally satisfied that no colza oil will yield a better result than ours under exactly the same tests. We have but one more experiment to make with colza; it is its extraction by chemical displacement. If this fails we shall abandon the whole business.

If all things are put together, I think the following statement will be allowed, to wit: Our colza oil is equal to any foreign colza. It is better than any we have heretofore made. It is better than sperm oil or any other burner, excepting only lard oil. Our failure then is owing to the superior excellence of lard oil, which, under the persistent investigation of the board, has been shown to be the best and cheapest safe illuminator available.

The board are entitled to great credit in producing this result. It will be remembered that but a few years since, lard oil was pronounced unsuitable for light-house purposes, but the perseverance of the board has brought out the fact that it is much the best and cheapest oil, and that the expenses of lighting the coast and harbors have been thereby greatly reduced. Surely the country at large should acknowledge this, and give due credit to the board. We have endeavored to do with colza what the board has effected with lard oil, and we have been unsuccessful both for ourselves and the light-house interest. The undertaking has been no source of profit to us, and had the capital and time that have been devoted to colza been used in our other branch of manufacture (linseed oil), it would at least have re-imbursed us with a fair remunerative return. As regards the oil we have offered, we have hoped the board would take it. I do not think we can improve upon the quality, and it is the last we shall venture to offer to the acceptance of the board, for we shall henceforth abandon the manufacture, except for local wants.

We are grateful to each member of the board for the interest they have always shown in our undertaking, and for their uniform kindness and courtesy. Accept, my dear Commodore, for yourself and your associates in the board, my warmest thanks for your many kind expressions of interest, and believe me, truly and gratefully, yours,

C. S. HAMILTON.

Com. A. A. HARWOOD, *U. S. N.*,
Secretary Light-House Board, Washington, D. C.

From the date of the introduction of lard oil in 1865, '66, and '67, until the end of 1873, when the attention of the board was again directed to the study of mineral oil, continual improvements were made in the processes of its preservation and inspection, and also in the lamps and other appliances for its employment, and nothing further as a

light-house illuminant was required. It is therefore with regret that we are urged, on account of the increased price of the article, due in some degree to the reputation as a burning material given it by the board itself, to substitute for it a less reliable but a much more economical material.

Experiments on Mineral Oils.—At the time lard oil was introduced, a series of experiments was made on the comparative value of the different petroleum oils used in this country. They were all considered too dangerous to be intrusted to the ordinary keepers of the light-stations of our coast. Since the date of these investigations however, improvements have been made in the manufacture of these oils, by which a much greater range has been obtained in the temperature at which they give off a noticeable vapor. During the last two years, a new series of investigations therefore has been made relative to these illuminating agents, of which we propose in the succeeding pages to give a brief account.

The crude petroleums of the Pennsylvania oil region are of a greenish or yellowish appearance, and have a specific gravity of 45° to 49° Beaumé at a temperature of 60° Fahrenheit. Some are so volatile as to evaporate rapidly at the ordinary temperature of the air, rendering it dangerous to approach an open cask of crude petroleum with a flame; others are much less volatile, requiring a temperature of from 200° to 300° F. to vaporize them. The volatility of the hydro-carbons is intimately connected with their specific gravity. They become heavier as the volatile ingredients are driven off by heat. The inflammability of the oils is also connected with their volatility and specific gravity. The light volatile oils ignite at ordinary temperatures, as we have said, on the approach of a burning match, while the heavier require a higher temperature for ignition. The process of manufacturing these oils consists in separating them from each other as they occur in the crude oil of the springs by what is called fractional distillation; for this purpose the crude oil is placed in an iron still provided with a worm of the same metal submerged in a tank of water

for cooling it; the still is then gradually heated; the first product that passes over is gaseous at ordinary temperatures, and can only be condensed into a liquid form by cooling the worm with ice, or by compressing the gas with an air-pump into a strong receiver. After all the vapor is given off at the temperature, say of 90° F., the temperature of the liquid in the still is raised, and it then exhales a vapor at a higher temperature and of greater density; and thus on successively, a series of liquids is produced, each of which requires to be heated to a higher degree before taking fire on the approach of a lighted match. The more volatile vapors are heavier than atmospheric air, and when suffered to escape from the cask containing them will flow along the surface of the floor of a room, and reaching a distant fire-place will ignite, and burning backward to the reservoir will set fire to the oil from which they emanated.

Many serious accidents have occurred in this way, by the firing of a canister containing petroleum oil which has been left open, although at a distance in some cases of from 20 to 30 feet from a lighted fire. Another source of danger from the lighted oils from which the more volatile vapors arise—results from the fact that these vapors when mixed with a certain portion of atmospheric air explode on the approach of a flame with extreme violence. When the proportions of vapor and air are equal no explosion takes place; but when they are in the ratio of 10 parts of the vapor in volume to 100 parts of air the explosion is most violent; when the quantity of air or of petroleum vapor is increased or diminished, the explosion is less violent until one or other becomes excessive, and when the vapor is in excess, it kindles without explosion, as is the case with ordinary street gas when issuing from the burner.

A notable case of the explosive quality of a mixture of petroleum vapor and air occurred in connection with the light-house service in 1864, on Lake Michigan. The keeper in one of the light-houses of this district substituted on his own responsibility an ordinary kerosene lamp of tinned iron for the usual lard oil lamp. This gave a good light

and required no trimming during the night; it burned well for several nights, and the keeper congratulated himself on the success of what he considered a very important experiment. Unfortunately however on the last morning that the lamp was used he attempted to put it out in the usual way by blowing the air from his lungs down the chimney, when an explosion took place, which scattered the oil in a burning state over the deck of the tower and also on his clothes. In his fright he ran down the stairs of the tower, and had scarcely reached the ground when a violent explosion was heard above, which blew off the whole lantern and broke the lenticular apparatus.

The explanation of these two explosions is not difficult. The burning of the oil during the night left a space void of the liquid in the reservoir of the lamp which was filled with air and vapor, which happened on this occasion to be near the explosive proportions; on blowing air down the chimney it mingled with the vapor, furnishing the quantity necessary for the violent combination, and consequently the explosion occurred which broke the lamp. The second explosion was caused by the ascent of the vapor from the burning oil on the deck, and took place when the quantity exhaled amounted to a tenth part of the volume of air present. The two then suddenly rushed into combination, producing the effects that we have mentioned.

Under favorable circumstances, this lamp lighted with kerosene might have burned silently for several weeks, but in accordance with the doctrine of chances, time enough being given, an explosion was inevitable. Facts of this kind in connection with the difficulty experienced in burning mineral oil in light-house lamps, induced the Light-House Board to adopt lard oil.

Various experiments have been made from time to time by the Light-House Board with a view to the introduction of petroleum as an illuminating material, as soon as oil could be obtained in this country of a suitable character, lard oil having advanced in price to such a degree as

to render this change desirable in an economical point of view. In the meantime experiments had also been made in France and England for the purpose of introducing mineral oil as a light-house illuminant, but it was not until 1873 or 1874 that the result was entirely satisfactory.

The process of manufacturing the oil has been very much improved in this country of late years, and there are now several companies which profess to produce oil entirely safe, and otherwise suitable for light-house purposes. In view of further experiments with mineral oil, an advertisement was inserted in the papers in 1874 requesting manufacturers to send samples of their oils to be tested at the Light-House depot at Staten Island, and in accordance with this numerous specimens were received and submitted to examination.

The first test to which the oils thus furnished were subjected was that of flashing; that is, the determination of the temperature at which the oil gives off a vapor which will flash into a flame on the approach of a small taper, or in other words which indicates the rise of a vapor which mixed with atmospheric air will tend to produce an explosion. The flashing temperature differs however from that at which the liquid takes fire as a whole. This will be understood if we suppose that two liquids have been mixed together, a light and a heavy one; the flash in this case will be due to the vapor from the lighter mixture, while the burning is due to the temperature at which the compound is fired. To make this flashing test requires considerable precaution. The oil to be tried is gradually heated by a spirit-lamp in a water-bath, a sensitive thermometer being suspended in the oil with the bulb slightly below the surface; the heat of the water is very slowly increased by moving from time to time the spirit-lamp from under the basin of the water-bath which contains the oil, and the point of flashing is obtained by passing over the surface of the oil a small flame until the first indication of flash is observed. The flame should not be so large as to heat the surface, and is best pro-

duced by a very small jet of gas from a glass tube drawn nearly to a point and connected with the gas pipe of the house by a tube of india-rubber, the quantity of gas being regulated by a stop-cock, so that the flame is a mere pencil of light about a quarter of an inch in length and a twentieth in diameter. The basin which contains the oil is about four inches in diameter, and is sometimes covered with a plate of thin glass, the thermometer passing through an aperture in this cover, and a larger hole being left open in the same for inserting the pencil of the flame. The basin containing the oil is sometimes left entirely open, the cover being discarded, but we do not think this as safe a method as the other. Great caution must be taken in raising the temperature very gradually, so that every part of the liquid may have the same heat and the thermometer thus truly indicate the temperature. If the rise of the temperature be very sudden, the thermometer will not respond, and the real flashing temperature will be higher than that which is indicated.

The next test was that of the firing of the mass of the liquid, which is sometimes 10 or 12 degrees higher than that of the flashing temperature; but generally the two are very near each other.

The next test was the determination of the specific gravity. This was obtained by weighing, in a glass flask with a narrow neck, an equal quantity of distilled water and of the oil in question; the ratio of the two, reduced to water as unity, gave the specific gravity required. To facilitate the operation, a flask containing just 1,000 grains of distilled water, was balanced by a permanent weight. The scales were tested by double weighing. The first series of weighings was made at the temperature of 74° F., that of the apartment in which the experiment was conducted; but oil and other substances change their bulk, and consequently their specific gravity, with a change of temperature. It is therefore necessary, in order that results may be compared, that the experiments be all made at the same temperature, or reduced to a standard temperature. The temperature

formerly adopted in England for specific gravity is 62° F.; but in the case of petroleum the temperature of 60° has been adopted in this country and England. In the first series of experiments made with the oils in question, the weighing was conducted at a temperature of 74°, as we have said, namely that of the atmosphere at the time. A series of experiments at a lower temperature was afterward made, in order to obtain a correction by which to reduce the specific gravity first obtained, to that of a temperature of 60°; but as each oil exhibits a different rate of expansion by heat, the process became very laborious. Experiments were therefore made to determine the correctness of indication of the specific gravity of the oils by means of a hydrometer. This was found to differ from that obtained by weighing within one per cent., and was therefore concluded to be sufficiently accurate for practical purposes.

To obtain the specific gravity of the oils by means of a hydrometer, a vessel of a depth of about 14 inches (containing say 10 gallons of water,) is provided; into this are introduced several glass cylinders containing the oil, and into these cylinders the hydrometers are plunged, the level of the oil being so far above the water that the under contact of the surface of the liquid with the scale may be observed. Before inserting the glass cylinders containing the oils into this water-bath, the liquid is brought to the temperature of 60° by mixing ice-water with it, at which temperature it may be kept for a long time, on account of the large quantity of the liquid and the great specific heat of the water. A change of temperature may be prevented by occasionally adding a small quantity of ice-cold water, care being taken to mingle the mixture by stirring. By this process the specific gravity at 60° of a large number of samples may be obtained in a comparatively short time. In this country and England the density or relative weight of petroleum oils is generally expressed in terms of the arbitrary scale of Beaumé, instead of that of the specific gravity. The following table gives the equivalent of the Beaumé scale in terms of specific gravity:

Beaumé's hydrometer for liquids lighter than water.

Degrees, Beaumé.	Specific gravity.	Degrees, Beaumé.	Specific gravity.	Degrees, Beaumé.	Specific gravity.	Degrees, Beaumé.	Specific gravity.
10	1·000	23	·918	36	·849	49	·789
11	0·993	24	·913	37	·844	50	·785
12	·986	25	·907	38	·839	51	·781
13	·980	26	·901	39	·834	52	·777
14	·973	27	·896	40	·830	53	·773
15	·967	28	·890	41	·825	54	·768
16	·960	29	·885	42	·820	55	·764
17	·954	30	·880	43	·816	56	·760
18	·948	31	·874	44	·811	57	·757
19	·942	32	·869	45	·807	58	·753
20	·936	33	·864	46	·802	59	·749
21	·930	34	·859	47	·798	60	·745
22	·924	35	·854	48	·794		

Another test to which the mineral oil was subjected was that of a reduction of temperature. For this purpose the samples were placed in an air-bath reduced to the temperature of 25° F. At this temperature several of the oils exhibited a thickened condition, especially those of the higher fire-test. The apparatus used for this purpose was the same as that previously described as employed in the case of lard oil.

The next test to which the oil was subjected was that of its liquidity. This test is of some importance in regard to lamps in which the oil is pumped up by machinery, and also as to the solid matter in the oil. It therefore gives a characteristic of the oil which with others serves to determine its degree of impurity. For this purpose the same method was employed as that described for determining the liquidity of lard oil. The liquidity exhibited by this process varied greatly in different oils.

All the experiments on the flowing of the oils were made at the temperature of the air, which was from 72° to 74°. In this case, as with lard oil, a marked difference was found in the time of flowing at different temperatures, and hence for comparison the experiments should be made at a standard temperature.

Another experiment was made to ascertain whether oils of

higher flashing test gave off a vapor at the ordinary temperature of the atmosphere; for example, at about 70°. For this purpose a barometer tube of about 33 inches in length, and an interior diameter of one-half of an inch, was filled with warm mercury, and inverted in a basin of the same metal. The finger was then placed under the open mouth of the tube in the basin and the tube slowly inverted so as gradually to pass the vacuum through the whole length of the column, and thus to gather up any particles of air that might adhere to the side of the tube; this left a space, when the inverted tube was held vertically, of about three inches of the open end of the tube unfilled with mercury; this being re-filled, the finger applied to the open end, and the tube again replaced with the open end downward in the basin, the vacuum produced by this process was nearly as perfect as if the mercury had been boiled in the tube, or the latter filled with the metal in a vacuum. After this, a small quantity of oil to be tested was drawn into a small glass syringe, the curved point of which being introduced beneath the open mouth of the tube under the surface of the mercury, a small quantity of the liquid was injected into the column; this rapidly rose by its levity to the top, and there a portion of it flashed into vapor, as was evident by the depression of the mercurial column.

From this experiment it is evident that kerosene—even of a high flashing temperature, does give off vapor at ordinary temperature. It is however of so feeble tension that it does not appear capable of producing explosion unless considerable time be allowed for its accumulation. It might not be apparent that although vapor was given off in a vacuum, it would be given off under the full pressure of the atmosphere; but it has been shown by the experiments of Dalton and others that vapors diffuse themselves in a space filled with atmospheric air with the same elasticity and quantity as in a vacuum, time only being required to produce the effect in the atmosphere.

The oils were also examined as to the remains of any free acid which they might contain, by simply immersing in

each sample a slip of litmus paper, which was suffered to remain in the liquid for 24 hours; under this test several of the samples produced a redness, denoting the presence of an acid which might corrode the metal of the lamps, also indicating the want of a thorough washing of the oil by an alkaline water.

Another experiment, which was exhibited to us by one of the proprietors of the oil which has a flashing test of about 140° F., consisted in lighting a lamp-wick charged with the oil and plunging it into a vessel filled with the same. The oil did not take fire, although the combustion of the wick was vigorous, and indeed the flame was put out when the wick was plunged beneath the surface of the oil. This experiment—which is frequently exhibited to the public, tends to give a sense of safety in the use of mineral oil which is at least in some degree fallacious. To illustrate this, the following experiments were made: First a slip of cotton cloth, about 6 inches wide and 2 feet long, was saturated with oil, having a flashing test of 140°, and suspended vertically from a ring-stand; a lighted match was then applied to the middle of the length of the slip, when it instantly took fire, and burned with a fierceness quite appalling.

After this, two pieces of cloth—one of cotton and the other of wool, were saturated with petroleum and placed flat on two pieces of tinned iron to protect the floor. On each of these was then dropped an ordinary friction match in the state of ignition. They both broke instantly into flames which soon entirely consumed the cloth, although but little air could obtain access to its under side, and notwithstanding the good conducting power of the tinned iron.

In a similar experiment made with the same kind of cloth saturated with lard oil, the cloth did not take fire when a lighted match was dropped upon it. Two cotton cloths of the same size were saturated—one with lard oil, the other with petroleum, and lighted at the same time. The petroleum cloth was consumed in 1 minute 23 seconds; the lard cloth in 5 minutes.

To render these experiments more strikingly applicable to cases of accident which might occur in a light-house, a

piece of cotton cloth about 2 feet square, which had been used to wipe the table on which kerosene had been spilled, was crumpled up into the condition of an ordinary dish-cloth, and thrown into a corner of the room. When a lighted match was dropped on this, it instantly burst forth into a most violent combustion.

These experiments are important in establishing the fact that oils which are commonly sold as entirely free from danger are not really so. They may be safe from explosions at ordinary temperatures, and in this respect are to be preferred to the lighter oils; but when spread over a large surface they burn with greater intensity, even (as I have seen,) on a surface of ice. Indeed, the results are so striking, that it might be well to repeat them in the presence of every light-house keeper, in order to impress him with an idea of the danger to be apprehended in spilling the oil over his clothes, or in carelessly dropping his matches on cloths which which had been used in cleaning the apparatus.

Among the peculiar properties of mineral oil is its great surface-attraction or power of adhering and spreading on other surfaces, as well as ascending wicks to a much greater height than other oils. This property is recognized by the house-keeper who finds the exterior of the lamp covered with a film of oil shortly after it has been subjected to a thorough cleansing. It rises along the interior surface of the lamp and spreads over the outside. On account of this property it can be freely burned in lamps of which the fountain is at a considerable distance below the flame, and in which no overflow is required to produce a brilliant combustion.

A series of experiments was next made with regard to the burning qualities of mineral oils of different densities, from which it was inferred that the lighter oils in lamps of the fourth order gave a greater amount of illumination than the heavier oils, and furthermore that the latter charge the wick more than the former, from which it would appear that in using mineral oil, while safety should be the prominent consideration on the one hand, in the choice of the material, regard must be had on the other, to the illuminating power.

In regard to the relative photometric power of lamps of the same order charged with mineral and with lard oil, all the experiments we have yet made on this point tend to the conclusion that in smaller lamps with the more volatile oils a greater photometric power is obtained than with the same lamp when charged with lard oil; but with the larger lamps the reverse is the case, the lard oil burned in these lamps giving greater power than the mineral oil.

An unexpected difficulty arose in the course of the investigations for the introduction of mineral oils, on account of the form of the flame. While a lamp with a constricted chimney, like that used in the German student-lamp, gave the greatest photometrical power, it was found that the shape of the flame did not correspond with the arrangement of the lens apparatus, a large portion of the light being thrown upward toward the sky and another toward the earth. It was only after a series of trials with chimneys of different forms and button-deflectors that a flame of the best shape was obtained. To compare these flames in actual use, they were placed in succession in a light-house, with a lens of the fourth order, and the photometrical power determined at different distances, from a mile to ten miles in extent, by interposing between the eye and the light a series of thin colored glasses, until the light was totally extinguished. It was found in these experiments that some of the flames which had an appearance of greater brilliancy near by, failed to produce comparatively the same effect at a greater distance. Having settled upon the form of the flame to be used in lamps of the lower orders, arrangements have been made for the introduction of mineral oils into all the stations in the third district, at which lights of the fourth and smaller orders are at present in use. The substitution of mineral for lard oil however is a matter of no small difficulty, and requires to be made with great precaution. An entire change in all the lamps is required; the several parts of the apparatus which in the case of lard-oil lamps were united by soft solder must now be joined with spelter.

The importance of this was evinced by an accident which

happened in the photometric room in the case of a lamp o the fourth order under trial: the heat unsoldered an air-tub and let down the oil from the reservoir on the flame, whic produced so fierce a combustion that it would have set fir to the building had it not been of fire-proof materials.

The gradual introduction of mineral oil will be mad as rapidly as experience indicates the best and safes mode of employing it. It has already been adopted in th smaller lamps for lighting the Mississippi and its principa tributaries. The substitution however is not on account o the superior quality of this oil in comparison with lard oil —since we think the latter as an illuminating material i inferior to no other at present in use,—but simply on accoun of the comparative cost of the two materials. This relativ expense will be definitely ascertained after we have deter mined the best form of lamps to be used. Experiments thu far have been principally confined to the lower orders o lamps.

ON THE ORGANIZATION OF LOCAL SCIENTIFIC SOCIETIES.*

(From the Smithsonian Annual Report for 1875; pp. 217–219.)

DEAR SIR: - - - - - In answer to your question, as to the plan of organization and operation of a scientific association, I submit the following:

The object of your society being—as you inform me, to cultivate "scientific taste and knowledge among its members," this object should be kept constantly in view, and care taken that it be not interfered with by a tendency to waste the time of the meetings in the discussion of irrelevant matters, especially those which relate to the government and organization of the establishment. I have been a member of several societies which failed to effect their object, by endless discussions on points of order or propositions as to the constitution and by-laws. There is in this country a tendency to express little thought in many words, to cultivate a talent for debate, or the art of making the worse appear the better cause—which is by no means favorable to either the increase or the diffusion of knowledge. The object of your society is not that of a mere debating club, but that of an association for the real improvement of its members in knowledge and wisdom.

It has been from the first, the policy of the Smithsonian Institution to encourage the establishment of such societies, on account of the great advantage they are to their members in the way of intellectual and moral improvement, as well as in the way of positive contributions to science.

Such an organization is an important institution for the advancement of adult education and the diffusion of interesting and useful knowledge throughout a neighborhood. The society must however be under the care of a few enthusiastic and industrious persons; it should adopt the policy of awakening and sustaining the interest of the greatest possible number of persons in its operations, and for this purpose the meetings must be rendered attractive. Care should be taken

*[Extract from a letter in reply to inquiries from a correspondent.]

to provide a series of short communications on various subjects, on which remarks should be invited after they have been read. Clergymen, lawyers, physicians, farmers, mechanics, and others should all be pressed into the service, and each solicited to contribute something, the object being to make the special knowledge of *each* the knowledge of *all*. I once belonged to a society conducted on this plan, which is still in existence, and a meeting of which I had the pleasure of attending about ten years ago; and by way of illustrating what I have said, permit me to mention the proceedings on the occasion in question. First a number of mineralogical specimens were presented and described, next a short paper was given on the local geology of the vicinity, and then a brief lecture on astrology, in which the process of casting nativities was described. This last subject—which on first thought might appear beyond the capacity of the majority of an ordinary audience, proved to be a source of interesting remarks, in which nearly all participated. This arose from the fact that astrological ideas and usages survive in modern civilization, and each one was enabled to give an example of beliefs and practices still existing in different parts of the country, as to the influence of the moon in various processes of agriculture, on disease, and even in relation to the survival of astrology in our language and general superstitions.

The farmer should be encouraged to bring to the meeting specimens of the various botanical productions which he meets with in agricultural operations, as well as specimens of the different soils of which his farm is composed. These should be referred to a committee, and their names and peculiarities given at a subsequent meeting. If a plant or a mineral or an animal is unknown to any member of the association, a specimen of it may be sent to this Institution, where it will be examined and after being properly labelled—returned.

The mechanic should be encouraged to give accounts of the processes which he employs, or of any facts of special interest which he may have observed in the course of his operations.

In short, all the members should be induced to observe, and also be instructed as to the method of observation. It is of vast importance to an individual that he be awakened to the consciousness of living in a universe of most interesting phenomena, and that one very great difference between individuals is that of *eyes* and *no eyes*.

What I have said relates to the uses of a local society in the improvement of its members; but the importance of an establishment of this kind should not be confined to the mere *diffusion* of knowledge. It should endeavor to *advance* science by co-operating with other societies in the institution and encouragement of original research. Thus it can make collections of the flora and fauna, of the fossils, rocks, minerals, &c., of a given region, of which the location of the society is the centre, and thereby contribute essentially to the knowledge of the general natural history of the continent. It can also make explorations of ancient remains, and collect and preserve the specimens of the stone-age—which still exist in many parts of our country, and to which so much interest is at present attached. Further, it can induce its members to make records of meteorological phenomena, many of which—of great interest, can be made without instruments, such as the times of the beginning and ending of storms, the direction of the wind, the first and last frost, the time of sowing and harvesting, the appearance and disappearance of birds of certain kinds, the time of the blossoming and ripening of various fruits, &c.; and as soon as the means of the establishment will afford, a series of meteorological observations should be entered upon with a perfect set of instruments.

In order however to give still greater interest to the society it should make arrangements in due time for the publication of its proceedings, to be exchanged for the transactions of other societies at home and abroad, the foreign exchange (if desired) to be made through this Institution.

I beg leave to assure you that the Smithsonian Institution will be happy to co-operate with your society in every way in its power.

THE METHOD OF SCIENTIFIC INVESTIGATION, AND ITS APPLICATION TO SOME ABNORMAL PHENOMENA OF SOUND.*

(Bulletin of the Philosophical Society of Washington; vol. II, pp. 162–174.)

Delivered November 24, 1877.

GENTLEMEN: I beg leave to tender you my sincere thanks for the honor you have conferred upon me, and the good feeling you have manifested toward me, by my re-election as president of this society. I say the good feeling which you have manifested toward me, because I know that there are many of your members who can much more efficiently discharge the duties of the office than I can. I may perhaps be allowed to say—without the charge of undue egotism, that I have never occupied any position for which I have been voluntarily a candidate. The several offices of honor and responsibility which I now hold—no less than nine in number, have all been pressed upon me without solicitation on my part, and I now begin to feel—in view of that peculiarity of human nature so admirably exhibited in the character of the Archbishop of Granada, that I ought to diminish the number of my responsibilities, gradually leaving to others the honor and the toil of office. It is therefore with no feigned hesitation that I again accept the re-election to the position to which your kindness has called me.

I have however taken from the first a deep interest in the society, knowing that it is intimately connected with the intellectual development of the city of Washington, and that it has a reflex influence upon every part of the United States. It tends to keep alive an active spirit of scientific advancement, not only to diffuse a knowledge of the progress of discovery among its members, but also to stimulate—by friendly criticism and cordial sympathy, to new efforts in the way of explorations into the unknown.

While but comparatively few qualifications are necessary for admittance, yet no person is elected who is not supposed

*[Anniversary address of the president of the Philosophical Society of Washington.]

to have at least a high appreciation of science, some familiarity with its principles, and capability of doing something in the way of promoting the objects of the association.

The general mental qualification necessary for scientific advancement is that which is usually denominated "common sense;" though added to this, imagination, invention, and trained logic—either of common language or of mathematics, are important adjuncts. Nor are objects of scientific culture difficult of attainment. It has been truly said that the "seeds of great discoveries are constantly floating around us, but that they only take root and germinate in minds well prepared to receive them."

The preparation however is not difficult, and many possess the requisites in an eminent degree who are not aware of the fact. Genius itself has been defined as a mind of general powers, determined—enthusiastically it may be, on one pursuit.

The method of discovery or of scientific observation is not difficult. There is a story in a work entitled "Evenings at Home" which produced an indelible impression on my mind. It is entitled "Eyes and No Eyes," and related to two boys who started on a walk during a warm summer afternoon. On their return one was fatigued, dissatisfied, having seen nothing, encountered only dust and heat; while the other was charmed with his walk, which had been over the same ground, and gave a glowing account of the objects with which he had met and of the reflections which were awakened by them. On this story De la Bêche has founded a work, entitled "How to Observe in Geology," which I would commend to the attention of every member of this society, while I suggest that good service would be done to the advance of knowledge were a similar work published relative to all branches of science.

Method of Scientific Investigation.—The first requisite for an observer is that his mind should be actively awakened to the phenomena of nature with which he is surrounded. Thousands of persons of excellent mental capacity pass through the world without giving the slightest attention to the ever

varying exhibitions which are presented to them. The sun rises and sets, the seasons change, the heavens every night present new aspects, but these to them are matters of course; they excite no interest, and it is only when some extraordinary phenomenon occurs, such as the blazing comet or the startling earthquake, that their attention is arrested. Another requisite is the power of the perception of truth, which enables the observer to recognize and define with unerring accuracy what he has seen without any tinge of color from *à priori* conceptions. Still another is the faculty of eliminating accidental conditions from those which are essential; and further, the characteristic of perseverance is indispensable.

The fields of scientific labor may be divided into two classes, viz., those which relate to the empirical observation of facts and those which relate to the systematic series of investigations as to the law or cause of special phenomena. As illustrations of the first class, may be specified the facts of the phenomena of the physics of the globe, those of ordinary meteorology and natural history; while as examples of the second, we have the phenomena of chemistry, physics, and astronomy.

The remarks I have previously made refer principally to the former. In order to elucidate the method of investigation, in the latter case, I will suppose the existence of a new phenomenon which is unconnected with any of the present generalizations of science, but of which it is desired to discover the law, or the facts with which it is associated. Such facts standing alone form no part of science; they are usually discovered in the course of investigations, and are of great importance in pointing out fields of new research which promise an abundant harvest.

The first step in the investigation is to re-produce the phenomenon; the next is to form in the mind a provisional hypothesis as to its cause; and in the choice of this we are governed by analogy. For example, if it appears to resemble some of the phenomena of electricity, we *assume* that it is produced by electricity; we next endeavor to ascertain by

what known action of electricity such an effect could possibly be produced: for this purpose we invent an hypothesis, or imagine some peculiar action of electricity sufficient to produce the effect in question; we then say to ourselves, if this be true, it will logically follow that a specific result will take place if we make a certain experiment; the experiment is devised and tried, but no positive result is obtained. In order to this negative result, the logical deductions must have been inconclusive, or the experiment must have been defective, or the hypothesis itself erroneous.

We examine each of the two former steps, and finding nothing amiss in them, we conclude that the hypothesis was not true. Another hypothesis is then invented, another deduction inferred, and another experiment made; still no result is obtained. At this stage of the research the inexperienced investigator is prone to abandon the pursuit: not so he who has successfully attempted to penetrate the secrets of nature. Undeterred by failure, he changes from time to time his hypotheses, makes new guesses, and again repeats the question as to their truth by means of experiment; until at length nature—as if wearied by his solicitations, grants him a new and positive result. He has now two facts, and an hypothesis to explain them; from this hypothesis he makes a new deduction, which is also tested by a new experiment; but now perhaps he obtains a result which although of a positive character, is not what he expected. He has however made an advance; he has three facts and an hypothesis to explain two of them. In this case he does not usually abandon his preconceived idea, but modifies it until it includes the new fact. With the hypothesis thus improved, he deduces—it may be in rapid succession, a number of new conclusions, the truth of all of which is borne out by the results of the experiments. The investigator now feels that he is on the right track; that the thread of Dædalus is in his hand, and that he will soon be in the full light of day: but usually the escape from the labyrinth is not so easy. In the height of his successful career it not unfrequently happens that a result is obtained diametrically op-

posed to his previous generalization, which conclusively forces upon his mind the conviction that he is still far from attaining his end; that he has not yet seized upon the fundamental principle of the phenomena, which have grown into a class under his hands.

At this stage of the inquiry his self-esteem is much depressed; he throws aside for a while his apparatus, refers to his library for new suggestions: the subject however is not discharged from his mind; it still goes with him, and is perpetually recurring; it is mingled with his dreams, and is seen associated with the every-day occurrences of life, until at length, in some happy moment of inspiration, it may be after refreshing sleep, the truth flashes upon him; he catches a more extended conception of the relations of the phenomena; a more comprehensive hypothesis is suggested, from which he is enabled to deduce in succession a large number of new conclusions to be submitted to the test of experiments. These are all found to yield the expected results, and the generalization which has thus been obtained is more than an hypothesis; it is entitled to the name of a verified theory. The investigator now feels amply rewarded for all his toil, and is conscious of the pleasure of the self-appreciation which flows from having been initiated into the secrets of nature, and allowed the place not merely of an humble worshipper in the vestibule of the temple of science, but an officiating priest at the altar.

In this sketch of a successful investigation which I have given, it will be observed that several faculties of the mind are called into operation. First, the imagination—which calls forth the forms of things unseen and gives them a local habitation, must be active in presenting to the mind's eye a definite conception of the modes of operation of the forces in nature sufficient to produce the phenomena in question: second, the logical power must be trained, in order to deduce from the assumed premises the conclusions necessary to test the truth of the assumption in the form of an experiment: and lastly the ingenuity must be taxed to invent the experiment or to bring about the arrangement of apparatus adapted to test the conclusions.

These faculties of the mind may all be much improved and strengthened by practice. The most important requisite however to scientific investigations of this character, is a mind well stored with clear conceptions of scientific generalizations, and possessed of sagacity in tracing analogies and devising hypotheses.

Without the use of hypotheses or antecedent probabilities, as a general rule—no extended series of investigations can be made as to the approximate cause of casual phenomena. They require to be used however with great care, lest they become false guides which lead to error rather than to truth.

It is not enough for a physical investigation that we have the simple idea, which may be embodied in a mathematical equation; we must see clearly with the mind's eye the operations in nature, and how the phenomena are produced in accordance with the well-known laws of force and motion.

An Investigation of an Acoustic Phenomenon.—As an illustration of what I have said, as well as an original scientific communication, I may be allowed to present in this connection an account of some observations on the phenomena of sound in its application to fog-signals, in which I have been engaged during the past summer, and which are an extension of the investigation of whose progress I have given an account at different times to the society.

This year my attention was again directed to the peculiar effect observed for several years past on the coast of Maine, which has been classed among those to which the term "abnormal phenomena of sound" is applied. In August, 1873, this was partially examined, and the result published in the Light-House Report for 1874. In order to investigate it further, I associated myself with General J. C. Duane, engineer of the first Light-House district; Commander H. F. Picking, inspector of the same district; Mr. Edward L. Woodruff, assistant engineer of the third district, and Mr. Charles Edwards, assistant engineer of the first district.

The phenomenon to be investigated was exhibited in connection with the fog-signal at a station called Whitehead, on

the coast of Maine, at the entrance of Penobscot Bay. It was reported as having been frequently experienced by the captains of the steamers plying between Boston and New Brunswick, and it had also been observed on two different occasions by officers of the light-house establishment.

The phenomenon, as reported by these authorities, consisted in hearing the sound of a ten-inch whistle distinctly as the station is approached till within the distance of from four to six miles, then losing it through a space of about three miles, and not hearing it again until within about a quarter of a mile from the instrument, when it suddenly becomes audible almost in its full power.

This phenomenon—according to the statement of the keeper of the light-house station, is noticed whenever the vessel is approaching the station from the south-west, and the wind is in the same direction. It is especially observed during a fog (when the warning of the signal is most wanted), and this is here always accompanied by a wind from the south or southwest.

Our first object was to verify the phenomenon, and for this purpose we steamed to the south-west, directly against the wind, which was blowing at the time with a velocity of about ten miles per hour; this fortunately happened to be the direction of the wind during which the phenomenon was most frequently observed. The whistle was sounded every minute by an automatic arrangement, and the time at which the several blasts were given could be noted from the vessel by the puffs of steam emitted by the whistle. As we increased our distance from the signal the sound very slightly diminished in loudness until the distance was about a half mile, when it suddenly ceased to be heard, and continued inaudible for about a mile farther, when it was faintly heard, and continued to increase in loudness until we reached the distance of four miles; at this point it was heard with such clearness that the position of the station could be readily located in the densest fog, but on proceeding still farther in the same direction it gradually diminished and was finally again lost.

As a second experiment we re-traced the same line back to the station, and observed the same effects in a reversed order. The sound was heard the loudest at a point about four miles from the station, and after that it diminished and became inaudible through a space of about two miles, and then suddenly burst forth nearly in full intensity at a distance of a quarter of a mile, and continued loud until the station was reached.

For the investigation of this phenomenon, we may assume provisionally that it is due to a peculiar condition of the atmosphere, either as to heat, pressure, or moisture, or a combination of all of them, which existed at the time in that part of the track of the steamer which may be denominated "the region of silence." But if this were true, such a condition of the atmosphere ought to be indicated by ordinary meteorological instruments. To test this, the temperature of the air was noted through the whole space by an ordinary thermometer, and also its pressure by means of an aneroid barometer, but no variation was observed in these instruments in passing through the air along the path of the vessel.

To complete this series of observations however the indications of a delicate hygroscope should have been noted. Unfortunately we were not provided with an instrument of this kind; the fact however that the phenomenon was frequently observed during a fog, or while the air is uniformly saturated with moisture, indicates that the phenomenon is not due to a difference of moisture in the region of silence. Indeed, it is sufficient to remember that a wind was blowing at the rate of ten miles an hour to be convinced that an isolated portion of air could not remain in a fixed position, even for an instant.

Another hypothesis might be assumed,—that the apparent silence was caused by the transverse reflection, in some way, of sound from the shore, but there was nothing in the configuration of the land which favored such an hypothesis.

The only explanation which presented itself was that of the upward refraction of sound, an hypothesis which has been

found fertile in new results in previous investigations of the same subject. To test this and to ascertain the dependence of the phenomenon on the wind, the position of the focus or the origin of the sound was changed. For this purpose the whistle of the steamer was sounded while a portion of the observing force was placed at the station; by this arrangement it was found that while the vessel, in reference to the sound of the signal at the station, passed through a region of silence, the observers at the station who gave attention to the sound from the steamer heard no interruption of the signal. This experiment was repeated each way, going to and coming from the station.

From this result it appears that the sound going *with* the wind was heard at every point on its course, while the sound moving against the wind was suddenly lost at a given point and not recovered again until a distance of more than a mile had been traversed by the vessel. This result was in strict conformity with the theory of refraction; in the case of the sounds travelling against the wind, the upper part of the wave would usually be more retarded than the lower, and consequently the sound wave would be thrown upward above the head of the observer. At a given altitude this difference of velocity would cease, and by the general tendency of sound to spread, the sound wave would again reach the earth.

But to test this still further, and to show that the locality was not an essential condition of the existence of the interval of silence, the experiment was repeated on the opposite side of the station, so that the sound from the fog-signal would move in the direction of the wind. Some of the observers were placed at the station and the others remained on board the vessel; both instruments were sounded, the one in the intervals of the sounding of the other.

In this case the sound from the fog-signal was continuous to those on board of the vessel through a distance of over four miles, and could probably have been heard many miles farther, but the progress of the steamer in that direction was stopped by the land.

From the report of the observers at the station it appeared that as the vessel passed into the distance but one blast was heard during its whole course. In this case (as in the preceding experiment of sailing to the south west) the sound moving against the wind was refracted upward, and as the whistle was but six inches in diameter it did not give sufficient volume to again reach the earth by spreading.

In experiments of previous years the fact has been shown that the sound is heard under certain conditions better when moving against the wind than in the opposite direction. This was notably the case in the experiments made at Sandy Hook in September, 1874, during which a sound from the west was heard at first *with* the wind about three times as far as a sound from a similar source was heard from the east, or *against* the wind; then the same sound was heard from the west three times as far as from the east after the wind had settled to a calm; and in a third observation the same phenomenon was observed after the wind had changed to a direction *opposite* to that of the sound, and had increased to a velocity of ten miles an hour from the east. These effects were afterwards shown to be connected with the fact that the upper wind during the whole day was blowing strongly from the west, and that the apparent changes of the wind were due to currents at the surface, and thus a sufficient explanation was given to the phenomena observed.

It would appear however from the investigations of last summer that the wave of sound which has been refracted upward may descend at a greater distance from its origin than even that at which sound moving with the wind can be heard, probably involving a peculiar case of undulating or compound refraction; but this requires further investigation.

Each series of observations gives rise to new questions, and indicates that the subject is one which is rich in new results. Unfortunately however the observations can only be made by the aid of steamers; and these—in the Light-House service, can only occasionally be employed in the rare intervals of more imperative duties.

In order to collect data for further use in the explication of the phenomena, the light-keepers at Block Island and Montauk Point (the eastern portion of Long Island) have been directed to blow the fog-signals for an hour on every Monday morning, each noting whether he can hear the sound from the other station; observing at the same time the direction of the wind and the apparent motion of the clouds.

From the result of these observations during the year it appears that the clouds give frequent indications of adverse wind currents, and that the number of times the sound has been heard against the wind is greater than the number of times it has been heard with the wind; a result which though unexpected—is not in discordance with previous assumptions.

It will be recollected by the Society that I have in previous years mentioned a remarkable phenomenon, which I have denominated the "*ocean echo.*" This has also been observed by the distinguished scientific adviser of the Trinity Board, and is considered by him as the key of all the abnormal phenomena of sound observed, and as a special illustration of the truth of his hypothesis that such abnormal phenomena are produced by invisible clouds of flocculent atmosphere. The phenomenon in question consists in a reverberation in the form of an echo from a point in the verge of the horizon to which the axis of a fog-trumpet is directed.

In regard to this, I first adopted the provisional hypothesis that this was produced by a reverberation from the crests of the waves of the ocean; but it having been stated that the same phenomenon is exhibited while the sea is smooth, this assumption must be abandoned, or in some way modified to suit the observed facts. To test the hypothesis of the reverberation being due to a reflection from an invisible cloud on the verge of the horizon, the trumpet of the large siren on Block Island was gradually elevated from a horizontal to a vertical position, and while in this position it was sounded at intervals for several days; but in no case was an echo heard from the zenith, but in every instance an

echo was returned from the horizon around its whole circumference.

In another experiment with a vertical trumpet at Little Gull Island, a small cloud, from which a few drops of rain fell on the area of the base of the light-house, passed directly across the zenith, and during this passage no echo was observed from the cloud, although the trumpet directed toward it was sounded several times in succession.

Again, in order to obtain additional facts in regard to the nature of this echo, observation was made from a vessel, by steaming out directly as if into the region of the echo—*i. e.*, in the direction of that point in the horizon from which the echo appeared to emanate.

In this case the loudness of the echo appeared to gradually diminish as we advanced, and to spread itself through a much longer arc of the horizon, while the duration of the echo increased in time.

It would follow from this experiment that the echo is not a reflection from a definite surface, since it would then increase in loudness as the surface is approached, but a series of rebounds from points at various distances.

Another fact of great importance in determining the nature of the echo is that derived from the observations of the keeper at Block Island. He has recorded every Monday during a year, the observations of the length of the continuance of the echo, the state of the weather, the direction of the wind, and the other meteorological data. Whence it is found that the echo from the sound of the siren is always heard during a wind in any direction, and of all intensities, but during the occurrence of a very high wind, with less duration after tne original blast, than in calmer weather; and above all, that it is heard equally well during a dense fog, when evidently the air must be homogeneous and saturated in every part with vapor.

From these facts it appears to me conclusive that the reverberation, constituting the *ocean echo*, cannot be due to invisible clouds. The only hypothesis suggesting itself to my mind as a basis for further investigation of this subject

—is that in the spread or divergency of the sound, the direction of the impulse turns through an angle of a little more than 90°, so as to meet the surface even of the smooth ocean in a direction by which it would be reflected to the ear of the observer, making the angle of reflection equal to the angle of incidence; although from the gradual dispersion of sound-beams, the precise equality of these angles is obviously not very important to the result.

On returning from this excursion by the N. Y. Western railway to the Hudson river at Troy, opportunity was taken to make some observations on the action of sound in the Hoosac tunnel, through which I passed, on the afternoon of September 7th, accompanied by Mr. E. L. Woodruff. Resting at East Windsor, near the western outlet, I spent a considerable part of the following day in making an examination of the work. Mr. W. P. Granger, the chief engineer, and Mr. A. W. Locke, his principal assistant, very courteously furnished a hand-car, and cordially proffered every facility for making any desired investigations. This tunnel (as is known to most of those present) is nearly five miles long, rising by an easy grade of 26·4 feet to the mile from either mouth to about the middle of the tunnel, where it opens into a vertical ventilating shaft through the rock—of upwards of a thousand feet in height. The top of this shaft opens between two ridges of the Hoosac Mountain, which rise respectively some 400 and 700 feet higher. From the middle of the tunnel when entirely clear of smoke, the distant opening at either end appears as a faint star. The darkness seems oppressive; and when a train is passing through, the air becomes so thickly clouded that the glare of torches cannot be seen at a distance of more than a dozen feet.

It had been constantly observed by those employed in the tunnel, that during the approach of a locomotive at no great distance, and a few minutes afterward, the sound of the engine was very much deadened and obstructed; so much so indeed as to imperil the workmen engaged in lining the top of the tunnel with a brick arch, who frequently failed to hear the locomotive until it was close upon them. This ob-

scuration of sound was not unnaturally attributed to the dense clouds of smoke constantly emitted by the locomotive; but this explanation can hardly be accepted as the true one, nor the condition noted as constituting even an appreciable cause of such acoustic opacity. When we reflect that a puff of exhaust-steam at high temperature is ejected at about every four feet of rail traversed by the driving wheels, it is not difficult to realize that in an atmosphere so systematically made heterogeneous there must be a very great amount of dispersion and absorption of sound waves struggling through such a medium. This has been well illustrated by the striking experiments of the distinguished physicist of the Royal Institution. A very simple method of confirming this explanation, and of eliminating entirely the effect of the smoke, would be the employment of locomotive engines driven by the combustion of coke or of charcoal. This experimental determination of the question did not occur to me till after we had left the tunnel; but on suggesting it to Mr. A. W. Locke, the assistant engineer in charge, he very obligingly undertook the conduct of such an experiment at the earliest convenient opportunity. The result has not yet been ascertained.

When the tunnel was entirely clear, and a gentle current of air flowing down the central ventilating shaft and out at the two ends (as is usual in the summer season, when the external temperature is higher than the internal), it was observed that a prolonged but irregular echo followed any loud noise, such as the sudden shutting down of the lid of a tool-chest. The unequal or somewhat intermittent character of the echo appeared to result from the irregular surface of the rock forming the walls of the tube. A somewhat similar echo is sometimes returned from the dense foliage of trees. It is proper to add that a very perceptible echo was heard from the portion of the tunnel lined with brick. The effect could in neither case be ascribed to any invisible "flocculence," as the air must have been in a very homogeneous condition.

Inasmuch as in such observations the waves of sound are

reflected back to the ear from points at a considerable distance from their origin, (this being especially true of the ocean-echoes,) we are liable to be seriously misled if we rely too confidently on the experiments of the laboratory, and form hasty generalizations from apparent analogies, without carefully considering *all* the meteorological conditions by which the rays of sound may be deflected, distorted, and diverged. It is now well established by numerous observations and experiments—made independently on both sides of the Atlantic, that the lines of acoustic propagation (conveniently called sound-beams) which are sensibly very rectilinear for the distance of a hundred or two hundred feet, and which are thus obedient to the katoptric and dioptric laws of precise focal convergence, by means of solid mirrors and of gaseous lenses, are yet at the distance of a few miles so strangely contorted and aberrant as seemingly to contradict all the analogies suggested by our experience with the rays of light. It is the accumulation of comparatively slight divergencies continued through many thousands of yards, whether under the influence of constant conditions or of changing and reversed conditions, which produces such marked anomalies at the distance of five or of ten miles, and which makes their investigation as laborious as it is instructive and important. And not until we have mastered all the conditions affecting the transmission of sound throughout its entire sensible range, and have thus become enabled to predict its true course, and to announce its varying limits of audibility at the earth's surface, under given circumstances, can we be said to have perfected the theory of this most interesting and indispensable agent of communication.

OBSERVATIONS IN REGARD TO THUNDER-STORMS.*

(Journal of the American Electrical Society; 1878; vol II, pp. 1–8.)

DEAR SIR: I highly approve the object of your society; and I beg leave to express the opinion that much valuable information may be collected and preserved through its organization, especially in regard to the phenomena of thunder-storms.

For this purpose it might be well to prepare a series of questions to direct attention to especial points of inquiry, and I take the liberty of suggesting the following as a contribution toward this end:

A.—Particulars of the Storm.—1. Give the number and time of occurrence of thunder-storms, so as to show their distribution through the months, days, and hours of the year.

2. Note the point of the horizon in which the storm generally arises in any given locality, and the point to which it tends.

3. Observe whether it usually divides into two storms at any point. If so, what is the topography of the surface below?

4. Determine the width of the storm from the extent of the surface covered by rain, and also (if possible by means of the telegraph) the length of its path.

5. Note the condition of the air before and after the storm as to temperature, moisture, and pressure; also the temperature of the water which falls.

6. Give the direction of the wind previous to the beginning of the storm, during its continuance, and after its ending.

7. Observe whether a calm precedes the violent part of the storm, and whether in front of it a curtain of dust is raised to a considerable height in the air.

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* [A letter addressed to the corresponding secretary of the American Electrical Society, dated Washington, D. C., October 13, 1877.]

8. Note the number of seconds the sound of a discharge continues, which will give approximately the minimum length of its path.*

9. Note the time between the appearance of the flash and the sound of the thunder, and also the angle of elevation; these will give approximately the height of the cloud.

10. Ascertain whether any hail accompanies the storm; if it does, note whether it falls along in two tracks or in one. In the former case, give the distance between the tracks. Give the size and character of the hail, whether it consists of an agglomeration of crystals, or of rounded masses stratified with clear ice and snowy concretions, and whether it contains in some cases small particles of dust or sand.

11. Note the number of discharges between the different parts of the same or different clouds, and also between the cloud and the earth. The former will probably be more frequent than the latter.

12. Note the color of the lightning, particularly if it be violet or purplish, which will probably indicate a cloud of great elevation.

B.—Effects of the Electric Discharge.—1. State what kind of trees are struck, and on what parts of the tree the effects are most apparent—on the branches, or the trunk.

2. What are the mechanical effects observed in the tree; is it torn asunder laterally, or is it broken transversely to the axis, or both?

3. Was the tree green or dry?

4. When a house is struck, state if it had a lightning-rod, and, if so, give its character, and especially its connection with the ground.

5. Mention the part of the house struck. If the chimney, was there fire in it at the time? Give the path of the discharge through the house, and its relation to conducting metals.

6. Note the inductive effects of the discharge in produc-

* The velocity of sound in open air at the temperature of 62° Fahr. is 1,125 feet a second, or nearly a mile in four and seven-tenths seconds.

ing sparks and flashes between different objects within the premises.

7. If the discharge passes through metallic conductors and disintegrates them, note any appearance which might tend to indicate whether the effect is produced by heat or by repulsive energy imparted to the atoms at the moment of the discharge.

8. If the discharge takes place between two surfaces, note if there is any apparent transfer of material from one to the other.

9. Note any peculiarity of odor that may be observed. All mechanical effects produced by the discharge should be mentioned, and special notice taken as to whether they are not in most cases produced by a violent repulsive energy given to the air in the path of the discharge, and whether the effects are greater in the direction of the axis of the discharge than in that at right angles to the same.

10. Note the effect upon man and animals; whether a part of the discharge passed through the body, or whether inductive shocks were felt.

A Notice of Two Thunder-Storms.—The following account of two thunder-storms which occurred last summer may perhaps be thought worthy the attention of your society, and of a permanent record in a scientific publication.

The first one I shall describe, and of which I had an opportunity to examine the effects, occurred at New London, Conn., where a violent discharge of electricity took place on the premises of Mrs. Alger, of that city. Mrs. Alger's house is situated on an elevation overlooking the river and the surrounding country, on one side of a lawn on which, at a distance of 150 feet from the dwelling, stood a tall flagstaff ninety feet high. Across this, at about twenty feet from the top, was a spar like the yard-arm of a ship, which was braced by two iron rods, joining the top of the mast with the two ends of the cross-piece. The lightning struck the mast, and brought the whole down to the ground. The upper part, including the cross-piece, came down unbroken, it being probably protected by the iron rods. The remaining seventy

feet of the mast was broken into larger and smaller fragments, principally at right angles to the axis, and scattered over the lawn in every direction. One piece—consisting of an entire portion of the mast six feet long and nearly a foot in diameter, was thrown ninety feet to the north, and another piece of about the same dimensions was projected ninety-six feet in an opposite direction. From the foot of the mast to different points of the compass a number of furrows were plowed in the earth. One of these was in the direction of the house, along the side of which—marks of the discharge were visible at intervals. These indicated the passage of a part of the electrical discharge to a sewer on the farther side of the house. Marks of the discharge were also observed on the inner walls.

The house was of wood, and the walls consisted of clapboards on the exterior, and lath and plaster within. The effects on the inside were especially noticed at two points, one of which was opposite an iron safe, and the other was a portrait, the gilding of the frame of which was deflagrated.

But perhaps the most singular effect was exhibited in an interior room of about twelve feet square, around the cornice of which, under the ceiling, was a narrow strip of gilt beading. Though this room was insulated from the outer wall, the gilt throughout the whole circuit of the room was entirely burned off, while the wall in the corner farthest from the mast presented a blackened appearance, indicating that the electricity had passed upward from the earth at this point, and probably down again through the same channel.

These effects are note-worthy on account of the immense energy displayed in disintegrating the mast, and in the projection of the two large pieces of it in opposite directions. It would appear from this, as well as in the case of trees struck by lightning, that the greatest intensity of the force is in the line of the direction of the discharge, the tenacity of the wood being greatest in this line.

I have heard of several cases in which the trunks of trees of considerable size have been separated into two parts, as if by violent repulsion in the line of the axis, and of one in-

stance in which the whole body of the tree was separated from the trunk, and falling into soft earth, was left standing in a vertical position.

The other phenomenon of the burned gilding in the inner room appears to me to be due to the action of what is called the return stroke. The house and all conducting material within it, before the moment of the discharge, supposing the cloud to be positive, were electrified negatively. When the discharge took place the tension was suddenly relieved and the natural equilibrium restored with such intensity that the effect described was produced.

The other storm occurred at Carysfort Reef light-house, Key West, Fla., about seven miles from the nearest land, on the 12th of April, 1877. This light-house is built in the water on a submerged reef, and consists of a framing of stout iron pillars or piles, each about 100 feet in length, arranged in the form of an octagon, with one pillar in the centre, interlaced at various points regularly with smaller iron rods. It is 122 feet in height to the top of the lantern. At about forty feet above the water is the keeper's dwelling, some forty feet in diameter, the roof and sides of which are of iron-plate, while the floor is of wood. From the roof of this dwelling, extending to the lantern directly above, is an iron cylinder thirteen feet in diameter, containing the spiral stairway.

The following account of the storm and its effects, is given in a letter to Capt. W. H. Heuer, light-house engineer, from C. D. Hawkins, lampist of the seventh light-house district:

"On the afternoon of the 12th of the present month (April, 1877) I noticed indications of a squall, and on consulting the barometer found it was falling. At sunset the wind was blowing rather fresh from the southward,—the sky being dark and wearing a thickened aspect. About 9 P. M. a very severe squall struck the light-house, the wind having increased to a perfect gale, which was accompanied by thunder and lightning. The thunder was of the most terrific character, resembling in sound an artillery duel. There was not exceeding one-fourth to one-half a second between the flashes of lightning. About 10:30 P. M. the light-house was struck. The report caused thereby resembled

the explosion of a shell under water at the distance of about 300 yards. Within thirty minutes the light-house was struck seventeen times: each stroke was most perceptibly felt, and could be heard in the keeper's closed dwelling, —resembling in sound the discharge of a shot-gun. Each time the light-house was struck it trembled violently from top to bottom. The whole air seemed pervaded with electricity, and on arising from bed, my bare feet coming in contact with the floor (which was wet from the rain beating in at the window), I received a severe electrical shock which caused my hair to stand straight, and I was compelled to jump into bed and put on shoes before I could venture again onto the floor. One of the men assisting me was so violently affected as to vomit; the other men were similarly affected. The storm continued furiously till midnight, at which time it abated a little until daylight, when the wind hauled to the westward, and at eight o'clock it was blowing furiously again. The storm continued unabated until sunset, when it subsided. On Saturday the weather was fine, and we continued our repairs. The storm was one of the most violent I ever experienced or heard of."

An additional fact to those given in this letter was obtained through Capt. Heuer from the same source, viz: each time the light-house was struck, the piles which formed the stable part of the structure seemed to become luminous. This appearance may have been an optical deception, produced by the reflection of the light of the discharge from the various points of the building. This appearance however is not without a parallel in the history of discharges of atmospheric electricity, vertical rods of iron at the moment of a discharge having presented a luminous appearance throughout their whole length.

The physiological effects mentioned were probably due to induction, since during the continuance of the cloud above the light-house, all parts of the building must have been in a highly negative condition, supposing the cloud to be positive. This condition in itself, without variation, would scarcely produce any perceptible effect on the bodies of the inmates. It would however be in a state of continual variation with the constant changes in the intensity of the action of the cloud above, especially at the moment of the discharge,

when a neutralization would suddenly take place, sufficient to produce through nervous influence—the phenomena witnessed. The shock received by the person in his foot on getting out of bed is in direct accordance with the well-established principles of induction. So long as the body was in a horizontal position in the bed, which is only a partial conductor, the inductive effect would be much less on it than on the wet floor and iron pillars. When the foot therefore approached the floor, a positive charge would pass from the latter to the former.

That any physiological effects should have been observed under the conditions in which the observers were placed could scarcely, from *a priori* considerations, have been anticipated. They were in a space entirely enclosed by metallic conductors, with the exception of the floor, and in such a condition it might be thought that they would have been completely protected, since the interior of a hollow vessel, (like that of a quart measure,) when insulated and charged, gives no indication of electricity. If a metal ball is suspended by a silk thread, and made to touch the interior of such a vessel charged exteriorly, and afterward transferred to a delicate electrometer, no sign of electricity is observed.

It should be remembered however that in the case of the experiment just mentioned the statical charge of electricity is nearly uniformly distributed over the sides and bottom of the vessel; whereas, in the case of a dynamic charge, the electricity may pass in greater quantity on one side than on another, and the equilibrium of the interior may not be preserved; or furthermore, in this case the diameter of the house being more than twice as great as its vertical height, it would be represented in the preceding experiment by a very shallow vessel in which a complete neutralization could not take place. But whatever may be the explanation of the phenomena, the facts stated are of importance in the theoretical consideration of the action of lightning protection.

With thanks for the honor conferred upon me by my election as a member of the American Electrical Society,

I remain, very truly, &c., &c.

OPENING ADDRESS TO THE NATIONAL ACADEMY OF SCIENCES.*

(Proceedings of the National Academy of Sciences; vol. I, pp. 131, 132.)

Read April 16, 1878.

GENTLEMEN: It gives me great pleasure to welcome you to another anniversary meeting of the National Academy of Sciences. We have only to regret that the room we offer for your use is not better adapted for the purpose; but we expect —with considerable confidence, that Congress will make the appropriation for a new museum building which has been asked for; and if that expectation is fulfilled, we can promise you with certainty that an apartment expressly adapted for the purposes of the Academy will be provided.

During the past year the departments of Government have applied to the Academy for information on two questions relative to the tariff on sugar, and to a series of changes proposed to be made in the material of the Nautical Almanac. A detailed account of these questions and the answers to them will be given by Prof. Hilgard, the home secretary, in his annual report.

Another matter, of which a full account will be given you by Prof. Fairman Rogers, the treasurer of the Academy, relates to a fund which has been established by a number of my personal friends, the income of which is to be devoted during the lives of myself and family toward our maintenance, and afterward, as in the case of the A. Dallas Bache fund, under the direction of the Academy, to the advance of physical science.

This entirely unexpected token of affectionate regard was made at a time when it was doubly grateful. After an almost uninterrupted period of excellent health for fifty years I awoke on the 5th of December, [1877,] at my office in the Light-House depot on Staten Island, finding my right hand

* [Address by the president of the National Academy of Sciences, at the opening of its session held in Washington April 16–19, 1878; read by the home secretary of the Academy.]

in a paralytic condition. This was at first referred by the medical adviser to an affection of the brain, but as the paralysis subsided in a considerable degree in the course of two days, this conclusion was doubted, and on a thorough examination through the eye and by means of auscultation and chemical analysis Dr. S. Weir Mitchell and Dr. J. J. Woodward pronounced the disease an affection of the kidneys. The paralysis of the hand was accompanied with paroxysms of pain through the region of the heart and with oppression of breathing.

Under the judicious and generous direction of Drs. Mitchell and Woodward and the constant supervision of my family physicians, Drs. N. S. Lincoln and G. Tyler, the paroxysms have subsided and I am slowly improving, and now enjoy the prospect of being restored in a measure to my former condition of health.

But I am warned that I must devote my energies with caution, and expend no more power, physical or mental, than is commensurate with my present condition; and in consideration of this I think it advisable to curtail as much as possible the responsibilities which devolve upon me in connection with the various offices which have been pressed upon me in consideration of my residence in the city of Washington and my connection with the Smithsonian Institution.

It will be recollected that five or six years ago I asked leave to resign the presidency of the National Academy, believing that there were other members who had more leisure, and were better qualified to discharge the duties than myself. I received however a circular letter, signed by a number of the principal members of the Academy, requesting me to continue to hold the office.

I must think that the idea of my special fitness for the position was founded on the supposition that it was necessary for the president of the Academy to be a citizen of Washington; but this idea has been found incorrect by experience, and it is proved to be sufficient for carrying on the business of the Academy with the departments of Government, that the home secretary should reside in this city.

I therefore ask leave to renew my request to be allowed to resign the presidency of the Academy, the resignation to take effect at the next meeting. I retain the office six months longer in the hope that I may be restored to such a condition of health as to be able to prepare some suggestions which may be of importance for the future of the Academy.*

CLOSING ADDRESS TO THE NATIONAL ACADEMY OF SCIENCES.†

(Proceedings of the National Academy of Sciences; vol. I, pp. 132, 133.)

Read April 19, 1878.

GENTLEMEN: I have been much interested in the proceedings of the present meeting of the National Academy. Although I have been unable to be present, except during a small part of the session, yet I have been made acquainted with everything that has occurred.

Whatever might have been thought as to the success of the Academy, when first proposed by the late Prof. Louis Agassiz, the present meeting conclusively proves that it has become a power of great efficiency in the promotion of science in this country. To sustain this effect however much caution is required to maintain the purity of its character and the propriety of its decisions.

For this purpose great care must be exercised in the selection of its members. It must not be forgotten for a moment that the basis of selection is actual scientific labor in the way of original research, (that is in making positive additions to the sum of human knowledge,) connected with unimpeachable moral character.

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* [Responses were made by Messrs. F. A. P. Barnard, and W. B. Rogers, and it was unanimously—

Resolved, That with every sentiment of sympathy and regard for Professor Henry, the Academy most respectfully declines to entertain any proposition looking to his retirement from the office of President.]

† [Address by the president of the National Academy of Sciences, at the close of its session in April, 1878; read by the home secretary of the Academy.]

It is not social position, popularity, extended authorship, or success as an instructor in science, which entitles to membership, but actual new discoveries; nor are these sufficient if the reputation of the candidate is in the slightest degree tainted with injustice or want of truth. Indeed, I think that immorality and great mental power actually exercised in the discovery of scientific truths are incompatible with each other, and that more error is introduced from defect in moral sense than from want of intellectual capacity.

Please accept my warmest thanks for the kind expressions of sympathy you have extended to me during this period of my illness, and for your personal partiality in refusing to accept my resignation as president of the Academy. I shall be thankful if a beneficent Providence extends my life during another year and grants me the privilege of greeting you again in a twelvemonth from this time—as successful laborers in the fields of science.

I can truly say that I entertain for each member of the Academy a fraternal sympathy, and rejoice at every step he makes in the development of new truths.

With my best wishes for your safe return to your homes, and for a rich harvest of scientific results in the ensuing year, I now bid you an affectionate farewell.

END.

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